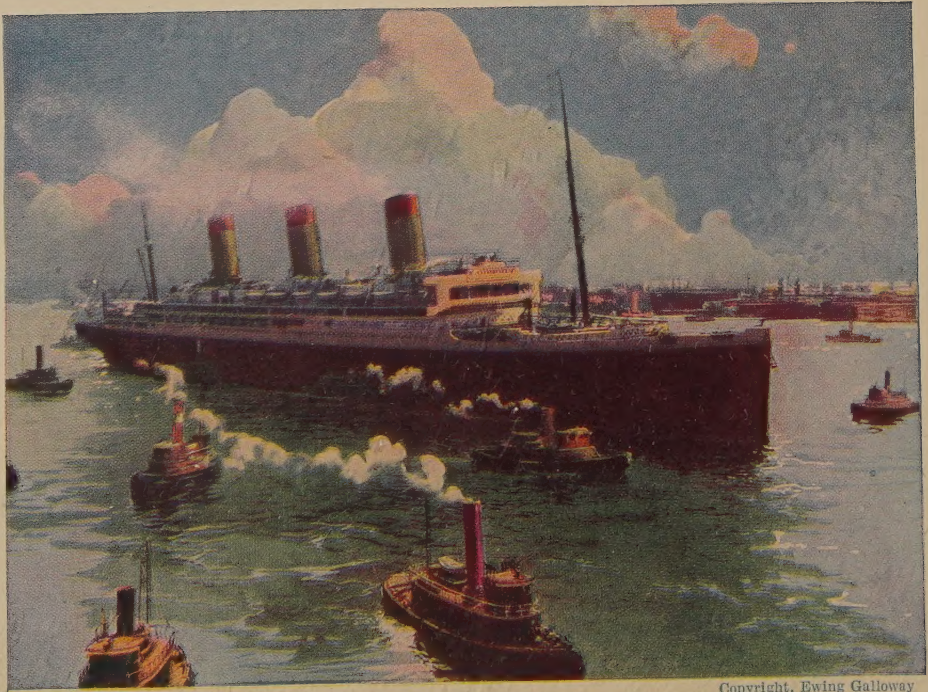

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ARRANGED IN SIXTEEN VOLUMES
WITH A HISTORY OF SCIENCE, GLOSSARIES
AND A GENERAL INDEX

SUPPLEMENTED BY A LOOSE-LEAF VOLUME EMBODYING
THE MOST IMPORTANT DEVELOPMENTS IN SCIENCE,
ANNUALLY FROM 1923 TO 1932

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VOLUME SIXTEEN

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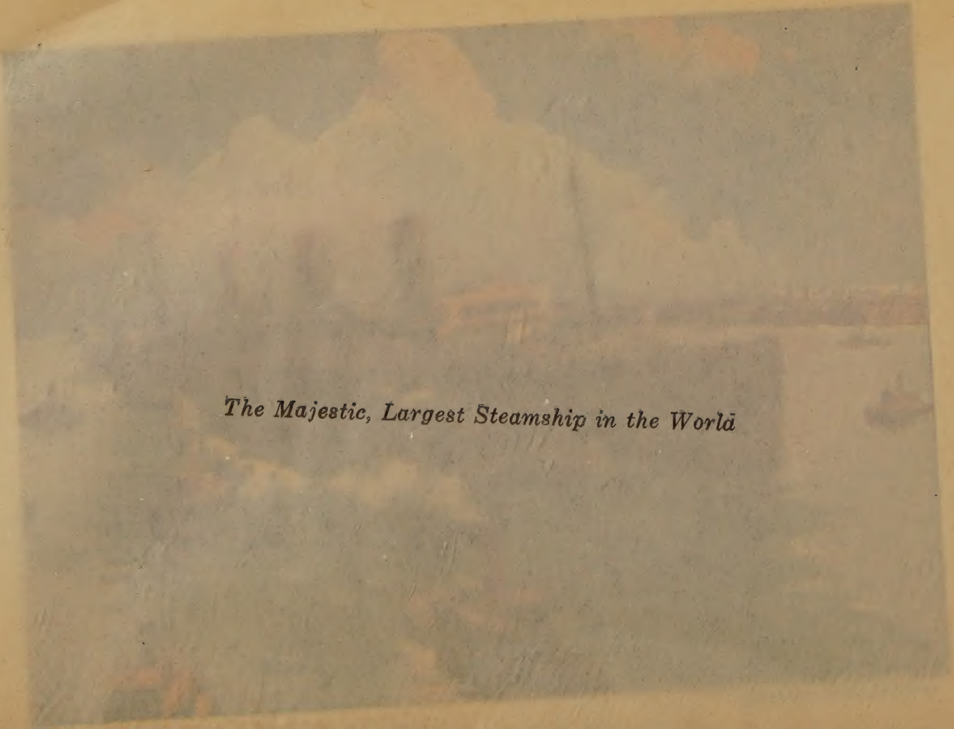

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HOW TO USE THE POPULAR SCIENCE LIBRARY

BY

GARRETT P. SERVISS

HISTORY OF SCIENCE

BY

ARTHUR SELWYN-BROWN

GENERAL INDEX

P. F. COLLIER & SON COMPANY
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PREFACE

THE final or Index volume of the Popular Science Library not only increases the value of this great set, but actually multiplies it. Volume XVI is in three parts: First, the editor, Garrett Serviss, in "How to Use the Popular Science Library," describes the way the reader may enjoy and profit most from its store of scientific knowledge in connection with his everyday experiences. Then follows Arthur Selwyn-Brown's "History of Science," an excellent foundation for the study of man's achievements in his struggle to understand and turn to his own use the forces of nature. Here is a concise record of progress from the earliest times until now—discoveries and inventions past, present, and about to come.

The third part of Volume XVI occupies nearly half the book. It is the General Index, which is as complete and as practical as it is possible for an index to be. Here, then, we have sixteen volumes on science, every work agreeable to read, every work complete in itself, and all of them, including the Index, prepared by specialists, each of whom has already gained distinction in the field he covers. The Index binds the collection into a consistent whole, making every bit of knowledge in the sixteen books available to reader or student without delay.

The style employed in the Index is a standard for such material. Volume numbers are represented by the Roman numerals, i, ii, iii, iv, v, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi. Pages are indicated by figures. All topics and subtopics are arranged alphabetically.

When you read or study the Popular Science Library, keep the Index volume at hand whenever it is convenient. It will add greatly to your interest and give you a depth of insight into these matters if you can compare one author's opinions and descriptions with those of another. If you are consulting the Library as a reference collection for information on particular topics, the Index will give you volume and page for every bit of text on the subject you are considering.

The Popular Science Library is unique in the number and standing of its authors and in the care that has been taken to make it the easiest as well as the most engrossing of all scientific collections for the reader or student to use.

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HOW TO USE THE POPULAR SCIENCE LIBRARY

THIS series of books is written for all the people and not for specialists only, though it is the work of specialists who know how to explain their subjects clearly and interestingly, without unnecessary technicalities and with keen appreciation of the popular and constantly increasing desire for scientific knowledge.

The supreme importance of science in the wonderful age in which our lot has been cast was demonstrated with overwhelming force of conviction by the events of the World War. If, as certain persons assert, science may be accused of having rendered war more destructive and terrible, yet, on the other hand, no one can deny that it was science that saved the world from sliding backward into an age of despotism.

The true importance of science for everybody arises from its rapidly increasing service in the development of human industry in all its forms, for industry is the mother of democracy.

Said Gabriel Lippman, the French physicist, inventor of color photography, who died in the summer of 1921: "For thousands of years science progressed by groping and feeling its way, and coincidentally industry got slowly on by guesswork; but within the last century science has developed more than during all preceding time, while industry has sprung upon its feet and begun to march with the strides of a giant."

Notwithstanding its immense importance and the vast extent and complication of its application in modern times, science is not really difficult for any person of ordinary school education and of good natural intelligence to comprehend, provided it is presented in a clear, plain, common sense manner, in popular language with illustrations drawn from everyday life and experience. The much talked-of methods of science are, after all, nothing more than the methods of common sense, applied with systematic care by minds disciplined to a high degree of efficiency. And, in fact, the only practical difference between the mind of a trained scientist and that of any other intelligent person is that the scientist has acquired a way or habit of looking at and thinking about things and events, which enables him to get at their inmost nature and meaning more swiftly and accurately than he could do if he went to work in a haphazard manner as, in truth, his forerunners of the earlier centuries were obliged to do. The pioneer must always work by rule of thumb, but when he has exploited his field he knows better ways.

Each branch of science has its own particular methods, but it is not necessary for the average reader to study these special methods in order to become able to grasp the facts and principles that have been developed by them. The results are all thrown into a common store—or should be if science is to attain its utmost usefulness to humanity—and from the common store the great public, the people at large, should be enabled freely to draw. The object of this series of books is to form such a store of science for the people.

It may encourage those who look with some degree of timidity upon the task of trying to understand the great discoveries and achievements of modern science to know that even the ablest scientists, leaders in their own particular branches, do not pretend, or attempt, to grasp the special methods or the technicalities of any division of science except that one in which their own work is done. They stand, with regard to other branches, practically on the same footing with the unscientific reader, having over him only such possible advantages as their special training in clear thinking and in the intense application of the mental powers may give them.

Besides, science is really the most interesting thing in the world—outside of men and women—and *they* would be less interesting, even to themselves, if science had not transformed their lives as well as their surroundings. If one of Voltaire's favorite messengers from some other, wiser world had visited our earth a few hundred years ago, or even only one hundred, and should now repeat his call, he would be amazed, and no doubt delighted, by the changes in every feature of life and society which he would find that science had brought about, as if by magic, during the interval between his visits. He would be likely to exclaim: "Some great teacher and trainer from a more enlightened part of the universe must have been here since I saw this world before. What a marvelous new spirit he has imparted to these creatures. Through him they have become more masterful and more like sons of God."

See if you can find a single detail of your daily life that is not affected by science, or upon which science does not throw new light. It is fascinating to trace out the scientific relations of the simplest things that surround us, or the most ordinary occurrences and incidents.

Start with your first awakening in the morning, and you will perceive that there is not a thing that you see, or that in any way attracts your attention, that is not touched and illuminated by science, and often in the most unexpected and delightful ways. It is by considering these things that one may best perceive how to use the volumes of this little library. As you open your eyes in the morning you see a bright glow through the window curtain, then you know that the sun has risen.

But stop a moment. What does that mean—"the sun has risen"? The sun has not "risen" at all. But, one of the greatest facts of the science of astronomy is illustrated before your eyes—a fact that it took mankind thousands of years to find out. You are standing in the astronomer's shoes now, if you choose to wear them. This is a part of his field of science. It took him a long time to convince the world that the "rising" of the sun in the east next morning after its "setting" in the west really means that the globular earth has turned half way over during the night. If this seems simple to you now, it seemed very hard to comprehend to our remote ancestors, who, though reasoning men like ourselves, had not learned as much about the relativity of motion as we now know, though even we may be puzzled by some of the consequences that Einstein has drawn from it. And a hundred other things that astronomy has discovered about the sun and the other suns, called stars, and the other worlds, called planets, immediately rush to your mind, and you turn to the volume on astronomy to read about them.

But this is only a beginning of the string of everyday incidents that are rendered curiously interesting as soon as their scientific relations and meanings become evident to you. Science is right at your elbow to raise questions and to answer them the moment you step out of bed, and your mind begins to work.

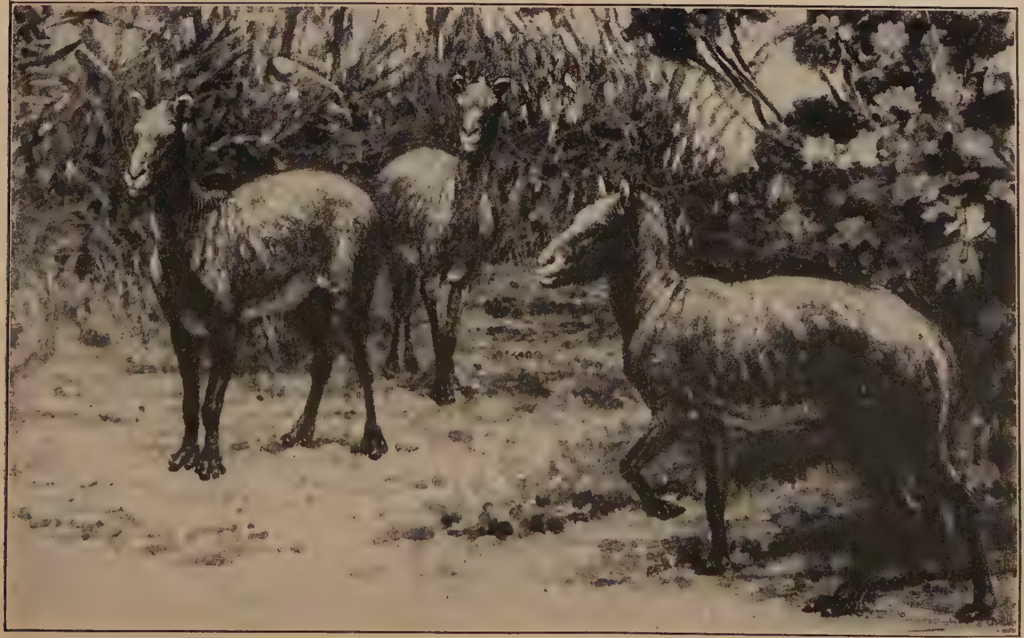
As you throw open the window to see what kind of a day it is going to be, whether fair, or cloudy, or rainy, cool or warm, you draw your conclusions from the appearance of sky and air, but in doing that you are entering another field covered by another branch of science and included in our little library—meteorology, or the realm of the air—and you may be sure that the correctness of the conclusions that you draw from the aspect of the clouds and the feeling of the air will be greatly increased, not only in certainty, but also in interest, if you read what the students of this subject have learned about the laws and the mysteries of the rains, clouds, cyclones, barometric pressures, great winds and genial breezes, great storms and little storms; in short, the whole wonderful science of the atmosphere, that invisible, yet powerful kingdom of the air, which we are just beginning to annex to our world of activities without regard to what its natural occupants, the birds, think of such an invasion.

Now you leave the window to begin making your morning ablutions. You turn on a faucet and take a drink, or plunge hands and face into the refreshing liquid, so cool, lively, and invigorating. But a bird or any four-footed animal may find just as keen physical enjoyment in the touch and taste of the water as you do. You, however, because you are a thinking being, possess a source of enjoyment from the touch and appearance of the water that is not open to those humbler creatures, and that source of enjoyment springs from the principles and facts of another branch of science which the mere sight of the running water may call to mind if you have caught the spirit of these books—the science of chemistry, whose early history is filled with that irresistible kind of romance that pertains to the search for Eldorado, or the strivings of the human spirit after the powers of magic; for the realm of chemistry was once a kind of semiscientific dreamland, wherein the "alchemists" delved at the same time for the "philosopher's stone" which was to turn base metal into gold, and for the wand of the magician which would give to its possessor the boundless gratifications of a Faust. Water is no mystery to the lower animals, but it is a great mystery even yet to the highest ones—ourselves—because we have been enabled to analyze it. You cannot look at it pouring from the faucet, and sparkling into bubbles, without recalling the fact that it is composed of two invisible, silent gases, and that chemistry tells us not only how to make the water disappear by taking those gases apart, but also how to form new water by making the two gases combine. The mystery is—why should this be so? It is a captivating question, and the business of the book on chemistry is to give you all possible light on the solution of that question, and others of a like nature. You will find, too, that the very latest chemistry has, strangely enough, discovered a sort of justification for the extravagant expectations of the ancient alchemists, by finding a way in which one substance may actually change, or be changed, into another, different substance—one "element" taking the form of another "element"—and also by getting clues to the existence of marvelous locked-up energies in matter, the release of which would give man control over powers that could properly be called "magical."

After finishing your toilet, with all the suggestions and remembrances of chemical science that it has produced, you start to quicken the circulation of your blood by catching up a pair of dumb-bells, or Indian clubs, or by pulling elastic cords, or banging a leather ball with your fists, as if you meant to go in for the championship of the world. Now, what taught you the value of such exercises? You are still on the ground of science, and you are practically demonstrating the principles of another of its branches—the science of health, or hygiene, which is a part of the subject of medicine, taken in its broadest signification, for, as the volume on that subject will assure you, the greatest service that this science can render to mankind is in teaching us the laws of our physical existence, and indicating, directly or indirectly, how all the functions of the body may be kept in the best working order by proper attention and exercise. You will find such things pointed out in the several sciences that deal with the body, such as physiology and medicine.

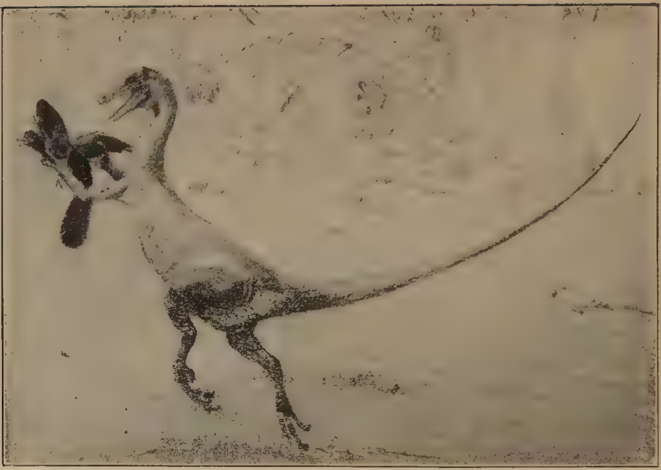
While you are making the leather ball strike the ceiling with resounding whacks, your dog, excited by the inspiring noise, bursts into the room, and interrupts your exercise with his enthusiastic morning greetings, expressed as energetically by his wagging tail as by his joyous barks and licks, all anticipatory of a lively morning run. He brings immediately into your mind the thought of still another division of science—zoology—to which you will devote many pleasant half-hours of reading, for it is full of most entertaining matter, as well as of matter calculated to awaken profound and useful thought concerning the relations of the many different members of the animal world to one another, and especially to their head and chief, man, to whom the supervision of the whole was, according to the Bible story, originally committed. Familiar as your dog may be to you, there are a hundred particulars of his family relationships, his descent from wild ancestors, etc., which can only become known to you through the studies that have been devoted to the science of zoology by curious-minded investigators from the times of Aristotle and Pliny down to our own day, when we have seen an ex-President of the United States wandering adventurously through some of the remotest portions of the inhabited globe, seeking fresh knowledge of, and personal acquaintance with, the rarer kinds of wild animals, and hunting down in their native wilds great beasts which the Cæsars used to admire from the security of the imperial seat, high above the bloody sands of the Roman arenas. And this modern ruler, after having laid down the political power intrusted to him by fellow citizens, found no occupation so attractive as that of adding something to the growing stores of science.

Next, your stomach, awakened to its wants and needs by the restored circulation resulting from your lively exercises, reminds you of what will be at the same time a pleasure and a means of sustained strength for body and mind, your breakfast. Breakfast properly comes under the supervision of the science of physiology. It is also suggestive of me-



Painting, Chas. R. Knight. (American Museum of Natural History)

THE LITTLE EOHIPPUS, FROM WHICH THE MODERN HORSE DEVELOPED



ORNITHOLESTES—PREHISTORIC ANIMAL OF AMERICA

Photo, Metropolitan Museum

HUNTSMAN, HORSE AND HUNTING DOG OF LONG AGO

From an ancient Cretan fresco

chanics and physics, since it has to do with the stoking of the furnace that keeps the bodily engine up to its work. Here you are face to face with a branch of science which you could no more safely neglect than an engineer or a fireman could neglect to learn the elements and principles underlying his critically important occupation. One of the first sciences to be systematically developed was that of man's body, including its structure, or anatomy, and its functioning, or internal action, physiology. You will find that correct ideas on these subjects were slow in being developed, yet even in the most ancient times men were shrewd and wise enough to understand the importance of knowing something about their own bodies, in order to be able to take proper care of them, and to deal with wounds and sickness.

It was an old saying that "the proper study of mankind is man." But that is a study which has two main branches. The first covers the subjects of physiology, anatomy, medicine, etc., while the second relates to that even more intimate part of ourselves which has ever been a fascinating mystery, and which we call the mind, or sometimes the soul. This is the theme of the science of psychology, whose name comes from that delicate, inscrutable spirit, *Psyche*, the Soul, which plays like a flitting sunbeam through the magical atmosphere of Greek mythology. Now, this subtle and exquisite science, often more poetic and mystic than scientific in its original character, presents itself in its more sober and practical dress to you as soon as, having finished your breakfast and prepared your bodily energies for the day's work, you begin to meditate on the problems of the day opening before you.

When you went to bed, perhaps your mind was agitated by some important matter of business through whose intricacies you could not clearly see your way. You turned and tossed on your pillow, and stated and restated the facts and arguments and lines of reasoning, but all the while they became more obscure and entangled until at last, in sheer exhaustion, you fell into a troubled sleep. But this morning, to your immense surprise and gratification, without any effort on your part, and while you are occupied with other things—putting on your clothes, hitting the ball, playing with the dog, eating your bacon and eggs, or what not—suddenly the elusive clue or solution, so vainly sought the night before, presents itself plain before you. In an instant, in the twinkling of an eye, the troublesome problem is solved, as easily and naturally as water runs down hill, and you are provoked at yourself for having been so dull and stupid as not to see it all before. But not so fast! You were stupid, to be sure, but it was not your mind's fault as you are now disposed to think, but the trouble lay in your physical fatigue. You were driving your brain too long without refreshment, and it became like an engine whose oil cups are empty. It could not receive and report the impressions of thought.

Now this kind of experience comes many times to many men and women, and it is the purpose of the book on psychology in this series to make everybody acquainted with the laws of the working of our minds through our brains. Yet, how many of those who are frequently puzzled by such things are aware that there is a branch of science, one of the most captivatingly interesting of all, devoted especially to this subject? By studying the volume on psychology you will get light on just such things as so greatly puzzled you, and haunted you, before the solution of your problem unexpectedly rose up, as it were, and stood plain before you on the breakfast table, after having for twenty-four hours resisted your utmost efforts to master it, or even to get an effective hold upon it. It is unnecessary to speak of the immense importance to all human beings of a knowledge of the laws governing the manifestations of the mind, by taking advantage of which they may get the most out of themselves with the least loss of time and expenditure of effort.

Let us keep on further along the wonderful road of science on which your feet begin almost unknowingly to tread from the moment of your awakening, and which they follow, often just as unconsciously, until you fall asleep at the close of another day; while, as we have just seen, even when we are asleep our minds are not altogether inactive, and may even secretly disentangle the puzzles of the day while our tired brains are restoring themselves with slumber. Perhaps you live in the suburbs of a city, or far from the business center, and have to take a considerable journey from your house to your place of work or business. Maybe you go by automobile, or by street car, or by a trolley route, or take a commuters' train. In any event, whether you drive your own car, or ride in one drawn by a motor or a locomotive engine, you are brought face to face with the science of physics, including, of course, not only mechanics, but also, in our own day, electricity and magnetism. If you glance at a steam locomotive, puffing and blowing, and then at a smooth, silent electric motor drawing a long train, and then at a swift automobile winding and turning with serpentine agility through crowds of slow horse-drawn vehicles—in all cases your memory must recall the long, hard road by which these things were brought about, and you must be lacking in intelligent curiosity if you do not resolve to know for yourself, not only the history of these triumphs of human invention, but the principles of action upon which they depend. If you have a car, it would be a good thing to drive it yourself and learn to take care of its machinery yourself, for thus you would go far toward mastering the elementary principles of the science of mechanics, which has done more than all other things combined to transform the face of the world we live in. You cannot, of course, acquire all this knowledge by practical experience, but by putting together what you observe with what you read in the volumes devoted to mechanics, physics, chemistry, electricity, etc., you will find that every day is a school day for you in which you have learned something new, useful, and interesting, and something, moreover, which every wide-awake person in this wide-awake age ought necessarily to know, and can know by pursuing such a course as that just suggested. Your morning's ride to work will be transformed into a delightful intellectual experience if you prepare yourself by a little daily reading to understand the construction and manner of working of all the machines, engines, and mechanisms presented on every side to your inspection.

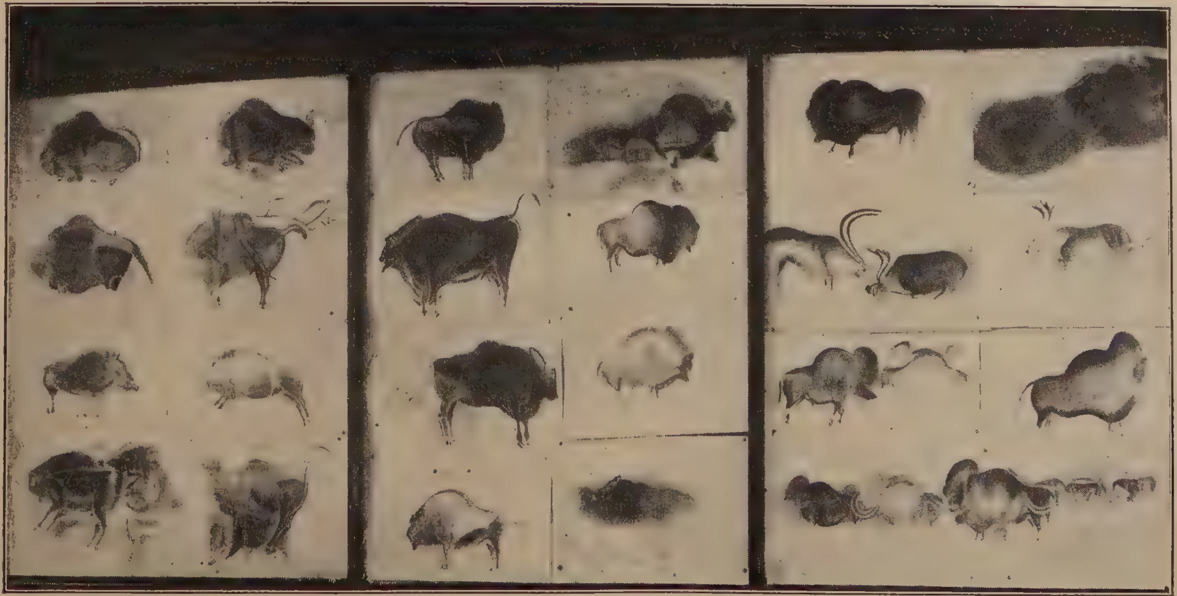
But machinery is not everything in life. Suppose that as you ride along your eye is caught by the great beauty of the flower gardens by the roadside, their blossoms bright in the morning sunshine and sparkling with the yet undried dew, as if sprinkled with diamonds. Perhaps your attention may never before have happened to be called so strongly to these objects, and possibly you have hitherto remained almost unacquainted with the names and peculiarities of some of the most common plants and flowers. But this morning, for some accidental reason, which may have a psychological origin, you are particularly charmed with the brilliant sight, and you resolve that you will be no longer ignorant of what could, manifestly, give you so much pleasure, besides being of unquestionable usefulness. When you return home you will take up the volume on botany, and it may lead you into a realm of mental delight previously unknown to you.

If it is the springtime, you may be interested by the sight of a tall, graceful tree, as lofty as a pine, and as straight in trunk, with many exquisite blossoms hanging from the pendulous stems on its great limbs, fifty or more feet above the ground, as if it were a flower garden in the air for the special delectation of the birds. Having never heard of a flowering tree outside the tropics, you feel a keen desire to know what this one is, and thus a way of introduction, founded on keen, personal interest, is opened for you to the science of botany. And few persons can take a ride, or a walk, anywhere in city or country or park, without having attention attracted by some unknown flower or plant, or tree, and without becoming aware how much pleasure is lost, and how much useful knowledge missed, by lack of the easily acquired knowledge of these things, which anybody can have by giving to it only that amount of time which would otherwise be wasted almost as completely as if the eyes were kept closed and the mind dismissed from its home in the brain. More mysterious, and not less fascinating than flowers and trees, are the birds and insects that flit by on their own errands. To explain them you have the volume on zoölogy, the science of animal life. Botany and zoölogy together go far to revolutionize the ordinary man's ideas about the attractiveness of outdoor life.

For the cultivator of the soil, whether farmer, gardener, or fruit grower, botany, of course, is the queen of sciences—though he may not safely remain ignorant of the others mentioned, which form a brilliant court for his queen. In no direction has science lately proved itself so indispensable as in the application of botanical knowledge to the improvement of agricultural operations of all kinds. In France, always one of the richest of lands in this respect, the government has since the war made special provisions for placing instruction in botany and plant physiology, and the results of all advances in the science of the vegetable kingdom, before the pupils of the primary as well as those of the secondary and higher schools. Botanical reading and study are encouraged in every possible way. One of the most significant propositions for the extension of this educational reform consists in the suggestion that the schools in the country districts give much more attention to the various branches of botanical knowledge than the city schools do, for the purpose not only of supplying instruction that will be of fundamental practical use to the young people who grow up on the land and are to make its cultivation their life's occupation, but also of stimulating a love of the country for itself, its scenes, its atmosphere, its society, its amusements, and its simple, beautiful, and healthful ways of life.

As your train, or car, rushes through a rock cut where the roadway has been carried, without change of level or grade, through the round back of a hill, you may happen to see on the side walls of the excavation curious striations, or cross checkings, of the rock surface, or alternate strata, or layers, of varying color and texture; some composed of smooth-faced stone, of a dark, uniform color, and others of coarse granular masses of variegated hue, some of whose particles flash like microscopic mirrors in the glancing sunlight that grazes the top of the cut. Here, then, you are plunged into the wonder world of the geologist and the mineralogist, the subject of one of the most interesting of our volumes. That man must indeed be dull of intellect who does not feel a thrill of interest at the sight of these signs and inscriptions, written by the ancient hand of nature in the rocks, and telling, in language far more easily decipherable than the hieroglyphics of Egypt, the story of the gradual growth of this round planet on whose surface we are confined, like flies or ants, as it rotates and revolves in empty space, circling with us around a star, ninety-three million miles away, called the sun, which saw the birth of our world and has ever since kept it warmed and lighted with its rays.

In those layers of rock in the railway cut you see the leaves of the book of geology, infinitely older than the oldest scripture from man's hands, and relating things that occurred in those far-off nights and mornings of time that flitted over the globe ages before the human stem had set off from the trunk of terrestrial life. These geologic pages speak of occurrences in the building of the world that happened millions of years ago, and millions of years apart, though they have left marks and vestiges that the eye can discern as easily as if they had been the work of yesterday. No observant person can ride twenty miles through the country, especially in a hilly region, without having the fundamental facts of geology continually before him, and all that he needs in order to comprehend these things is a little preparatory reading, accompanied and followed by intelligent thought and observation. Anybody to whom all rocks look alike, and all hills the same, needs a little awakening of the mind. He is one of the persons had in view when this series was conceived and written, and he has no occasion to feel in the slightest degree offended by such a statement, for the simple fact that probably ninety-nine one-hundredths of his fellow citizens, and they among the best in the community, are just as unfamiliar with the plainest facts of geology as he is. Geology is not a difficult science to master in its main outlines, and there are few more fascinating when once its drift is caught. Even the beginner in the reading of the volume on geology, by seizing such chances of observation as every ride or walk affords, may in a very short time acquire the ability to read the history of a landscape from its face, to recognize the work of the glaciers in the great Age of Ice, to see where ancient streams flowed, or where molten rock has gushed up through the surface layers of the earth's crust, and even to recognize on sight some of the fossils, which are under everybody's feet in some parts of the country, and which still retain the forms of animals some of which were among the primal inhabitants of the earth, whose lines have died out, while others, though their individual lives expired tens or hundreds of millions of years ago, bear in their fossilized forms a close resemblance to modern relatives and descendants whose generations still



EXHIBITION OF COPIES OF PREHISTORIC PAINTINGS FROM THE CAVERNS AT ALTAMIRA, SPAIN

Painting by Chas. R. Knight. Photo, American Museum of Natural History

THE SABER-TOOTHED TIGER THAT ROAMED OVER NORTH AMERICA IN PREHISTORIC TIMES flourish in the living world in this twentieth century of man's latest historic era.

Presently, turning from the attractions of the outdoor world, which seem just as entrancing the hundredth time you look upon them as they did the first time, particularly if you have cultivated the habit not merely of noticing but of thinking and reading about them, you take up the morning newspaper, in which most of your companions of the car are already deeply buried, and amid the political news, the personal gossip, the inevitable exploitation of the deeds of criminals, the foreign intelligence, and the social gossip that falls under your eyes, your attention is caught (this is an actual happening of not long ago) by the headline: "John Daniel, the orang-utan, is dead." This sounds odd. There has been no animal's obituary in the papers since Barnum lost his biggest elephant, and bequeathed its skeleton to science. You read further and find an interview with a professor about the human relationships, or apparent relationships, of the anthropoid apes, of whom "John Daniel" would probably have been the acknowledged king if his relatives of the woods could have understood the regard in which he was held by his white-skinned and clothes-wearing jailers. You will probably cut out that paragraph and put it aside for further consideration, remembering that there are at least three volumes in your Popular Science set at home, that on zoölogy, that on geology, and that on anthropology, in which there will be an abundance of interesting and authoritative matter bearing on this most important subject—for important you will consider it now that the death of a kind of caricature of humanity in the zoölogical garden that had so long amused the children as well as their elders with its humanlike motions, habits, looks, and pranks, has suddenly brought the whole question up among the news of the day, affording you a new light on a matter which you had hitherto thought to belong exclusively to the field of the professors of zoölogy and their students. Hereafter you will be disposed to take a broader view of all these things, and will be in a better position to understand and enjoy the discussions of learned scientists when they are interviewed by newspaper men on subjects of this kind. The inquiring spirit of the time requires this concession even if in your private opinion there is no real relationship between men and apes. And, without regard to any such questions, you will find the volume on anthropology immensely interesting and informing.

Finally, as your morning's trip comes to an end, your attention is recalled from the natural to the mechanical sciences. You descend from your car or train and take a ferryboat, or an elevated or subway train, to go to your office. Your now fully awakened mind, alert to all the scientific relations of everything about you, can no longer keep from dwelling upon the underlying meanings of this marvelous display of realized human dreams. With the speed of the wind you are carried deep under the city's pavements, inclosed in a little flying parlor, in the midst of an artificial subterranean daylight, far beyond the reach of the solar rays, emulating the self-luminous creatures of the deep sea bottom; or you go shooting past the windows of third, fourth, and fifth stories, or even above the levels of roofs, and you cannot but reflect and marvel that electricity does it all; electricity, that strange imp with blue star eyes no bigger than pin points, and a child's crown of little crinkling, piercing rays, which seemed so amusing when you were at school in the old days of frictional electric machines, when it was a great joke to give the cat a shock and see her flee with a squall, her hair standing on end in spite of herself. But now electricity has become a giant of unrivaled and terrific power, spurning the heavy-limbed Brobdingnag, steam, from its swift path, and fast making the world all its own—except its master, man, who is still, however, half afraid of his new and all-capable servant.

This modern genie of limitless power, conjured out of his deceptive bottle, can do the smallest as well as the greatest things for you. When, upon reaching your office, you telephone to your wife that Mr. Blank will be home to dinner with you, you cannot form the slightest idea of how the miracle of distant speech is accomplished unless you are either an electrician yourself, or have read intelligently upon the subject of the applications of electricity to the motivation of all kinds of machinery, a subject to which an entire volume is devoted in our series. It would be a kind of shame and reproach to an intelligent man to be ignorant of the way his telephone works, and of the simple scientific principle on which it is constructed. If telephones, and such things, were products of nature and grew on trees, we might be excusable for not knowing exactly their secret; but being made by men, with the same limitations as those that circumscribe us all, we ought at least to understand them.

Thus, by a simple review of the series of common happenings that arrive every day to everybody, we perceive how intimately and indissolubly the various branches of science treated of in this compact library of science, are linked with all that we do, including our most unconscious acts and our most habitual subjects of thought. We have taken for illustration the morning history of a person supposed to live amid urban or suburban surroundings. Equally illuminating would be that of an inhabitant of a village or a rural district, and even more suggestive in many respects. The dweller in the country is brought into closer association with the infinitely changing aspects of nature than the city dweller enjoys. The simplest incident in the life of a person living on a farm may be the beginning of a thread of connection leading, like the clue of a labyrinth, into the heart of some of the most marvelous departments of science, and resulting in a mental revolution for the fortunate person who follows out the clue under such guidance as these volumes afford. The writer has remembered from boyhood the indelible impression made upon his mind by the finding of an Indian arrowhead in a recently ploughed field. The shapeliness of the beautifully chipped piece of flint, almost as translucent at the edges as horn, the delicate tapering point which, as if by miracle, had remained unbroken probably since colonial times, the two curious little "ears" carefully formed on each side of the flat triangular base to facilitate attachment to the head of the arrow, and the thought, suggested by older persons, that this weapon might actually have been used in some midnight attack on a white settlement, made more terrifying by the frightful Mohawk war whoop and the display of the reeking scalps of human victims in the glare of burning stockade and cabins—all these things bred a keen desire to learn the particulars of the history of the red warriors of the Five Nations, the "Romans of the New World," and also to know something about the life and customs of this strange, savage race of mankind which continued to live in an "age of stone" on a continent that had never known civilization. No volume like that on the history and development of man in this series existed at that time; but if such a book had existed and had fallen into the hands of the finder of the arrowhead, it would surely have fascinated him more than "Robinson Crusoe" did, because a boy can distinguish as readily as a grown person the superior interest of the true over the pretended, provided that the true possesses the real elements of romance.

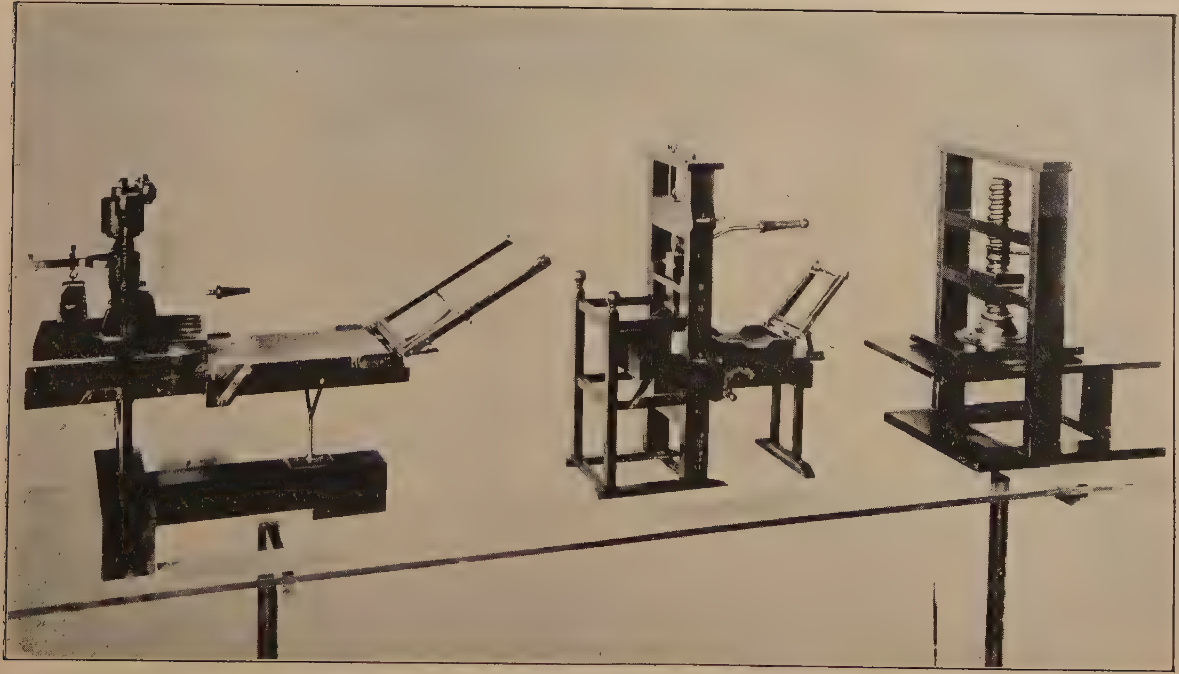
So, too, the writer remembers having an interest in mineralogy awakened in his mind, never to be obliterated, by the sight of another plowed field, in the southern skirts of the Adirondack Mountains, whose freshly turned furrows glittered in the sunshine with thickly scattered quartz crystals, some of the larger and more perfect of which blazed across the whole breadth of the field, like huge diamonds, and made the heart of the finder beat with an excitement akin to that of the discoverer of a Koh-i-noor. There were also some very curious "stone buttons" which one could break out with a hammer from slate rocks along the Schoharie Creek, and which, when cracked open, were found to be composed of pyrites that resembled pure silver—and sometimes gold—freshly broken. Now, things of this sort are always attracting the attention and awakening the curiosity of children living in the country, but the real pleasure and instruction that they might afford are usually missed because of the lack in the family library of popularly written books on the natural sciences—a lack that we are trying to supply.

For city children and their elders, whose eyes are constantly greeted, not by hills, creeks, ponds, rivers, woods, and fields, but by sky-aspiring buildings, railroads elevated on stilts, multiple-decked suspension bridges, electric power houses, tunnels that form a second city underground, and the thousand marvels and splendors of electric illumination at night, the volumes on physics, mechanics, and electricity and magnetism have a more immediate interest and value. What the children learn about these things in school is far from sufficient to satisfy their curiosity. They need books at home to guide their inquiries as well as to answer them. Only by that means can the diffusion of scientific knowledge, and the popularization of the scientific method of getting at the truth and the meaning of things be thoroughly effected. Science, as its history plainly demonstrates, progresses most rapidly only when a great number of minds have been led to concentrate their powers upon its problems. Great genius, it is true, rides over obstacles; yet consider how much further its energies might have carried it if the obstacles had been more or less completely removed in advance. Many a young man has been led to a brilliant career, to the great advantage of his country and his time, as a result of the interest awakened in him by the clear statements of a popularly written book on some branch of science.

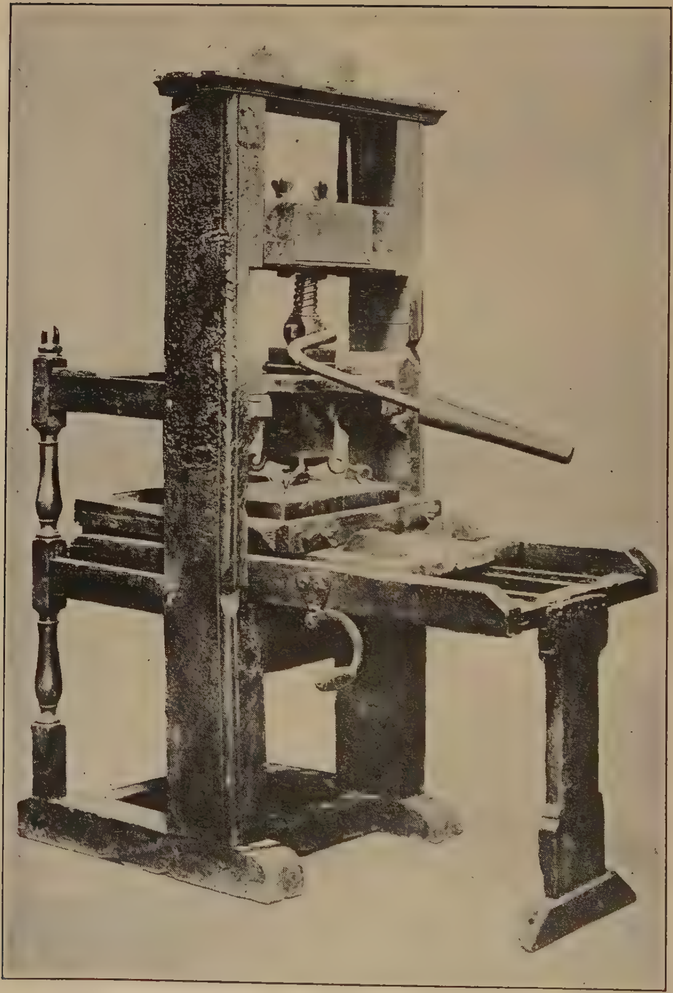
One of the difficulties that persons unfamiliar with certain branches of science encounter in reading about them arises from the excessive use of technical terms, the lack of simple illustrative examples, and also, sometimes, a lack of sympathetic appreciation of the reader's difficulties. It has been a special object of this series to avoid this trouble. Ordinary textbooks are prepared for students in school and are intended to be supplemented by the personal instruction and guidance of a teacher, standing at the pupil's elbow, or readily approachable. But the reader who wishes to inform himself upon some progressive branch of science after his school days are over needs to have the teacher included in the book itself.

Then, too, there are many persons who have no comprehension of the great and gratifying power that a knowledge of some of the elementary principles and formulas of science bestows upon anybody who may take the little trouble necessary to master them, a trouble that does not imply a long course of scientific study. The "man in the street," if he possesses these easy-working keys to knowledge, can verify for himself some of the calculations of scientists which, if he did not know how they were done, would always remain for him in the category of the mysterious achievements of genius.

To illustrate, let us take a simple example—that of the Newtonian law of falling bodies. Many persons would assume on the face of it that there was nothing in this law that could have a particular interest for them. But let us see. You will find in the volume on physics that the law is stated thus: $S = \frac{1}{2} gt^2$, i. e., "S equals one-half of the product of g multiplied by t squared." As you look at it you would, perhaps, as soon think of picking up a complicated tool and trying to use it for some ordinary purpose. Nevertheless, let us try. "S" in the formula means the space or distance traversed by the falling body, "g" means the velocity that the force of gravity imparts in each successive second to the body, and "t" means the time elapsed during the fall. What the formula tells us, then, is that if we observe the time during which the body is falling, and then square the number of seconds involved (multiply the number by itself), multiply this square by "g," which is represented practically everywhere on the face of the earth by the number 32, and finally divide the whole by 2, we shall have the distance that the body fell. This distance will be in feet, since the number 32, representing "g," is in feet. Now, it might be a matter of life and death, or at any rate of mental discomfort against quietude of mind, to have that rule in memory and to be able to apply it. For instance, you are on your vacation and stopping in a strange hotel, where they have put you in the top story. On looking out of the window you are dismayed at finding no fire escape, or other appliance of safety, so that your only resource in case of fire would be to make a rope out of the bedclothes and let yourself down with it. But, how far is it to the ground? How long should the rope be? Are there sheets enough on your bed to furnish it? The little formula about falling bodies will answer the question for you in five minutes. First, you let some small solid object drop from the window, and note by your watch, or by counting seconds, which everybody ought to teach himself to do, how long it takes to reach the ground. You repeat the experiment two or three times to make sure. Say the time comes out three seconds. Very well, now apply the rule: The square of 3 is 9, and 9 multiplied by 32 gives 288, and dividing by 2 you have 144 feet for the height! It is to be feared that your bedclothes rope



MODELS OF GUTENBERG'S PRINTING PRESSES



BENJAMIN FRANKLIN'S PRINTING PRESS

The original is now in the National Museum at Washington would not be long enough; you had better send to the office for something to supplement it. But if the time of fall should be only 2 seconds, which is more likely, except in skyscraper hotels, then the calculation would give you 64 feet for the height, which you might manage with the aid of the bedclothes.

This is only a single example among many that could be given to show the usefulness and interest of many of the formulas of science which the ordinary reader looks upon as beyond the reach of any person whose occupation leads him another way. But cases of equal simplicity could be found in connection with the subjects of electricity and magnetism, chemistry, medicine, physiology, etc. Sometimes it happens that a technical word contains its own definition and explanation in a nutshell. A striking instance of this will be found in astronomy, in the word "light-year." The meaning of this word stands forth on its face—it evidently expresses the distance that light travels in the course of one year. Now, since it is known by means of direct measurement that light goes at the rate of 186,300 miles per second, manifestly a light-year must be equivalent to an enormous number of miles. In fact that number, roundly stated, is no less than 5,860,000,000,000. But to what marvelous regions of thought such a term opens the way! Yonder star is 2,000 light-years distant from the earth; then its light-waves now entering your eyes left it when Julius Cæsar was conquering Gaul, and have been speeding on their way to the earth ever since! Another star is found to be 5,000 light-years distant; then the light by which you now see it started from the star when Abraham set out from Ur of the Chaldees to settle in the Holy Land, and has not found a resting place anywhere in boundless space until just now when its tiny waves break and expire on the retina of your eye! Such treasures of knowledge and tonics to thought are scattered all through the volumes of this set, the purpose of whose publishers, editors, and writers has been to accumulate such things in small compass and in crystal clearness, for the use not only of those who, after their school days are over, still wish to keep abreast of the progress of science in all its branches—as everyone should strive to do in this most scientific of all ages—but also for those who have hitherto not had the time, or the opportunity, or perhaps even the desire, to make themselves at home in the house of science.

It may be well to add a few words on the interrelation of the different subjects treated in the various volumes of the series. This will suggest to the reader himself the best order in which to take up the reading of the books. Naturally he will desire to obtain both a clear general view of the whole field of science, and also more detailed acquaintance with its special parts, the amount of detail depending upon his particular interest in a subject. For the first purpose the preferable way would be to run first over the brief account that follows in this volume, of the history and development of science in general, and then to take up the simpler and more easily grasped branches.

But it should be firmly kept in mind that, fundamentally, science is one, having in all its branches but one aim and object, viz., the ascertainment and demonstration of the exact truth of things as far as human capacities are able to reveal and comprehend such truth, and also but one method of procedure, which is the method of common sense trained to the utmost attainable exactitude in observation and the greatest possible clearness and precision of reasoning. Science properly so-called confines itself to things that are subject to observation by the senses and to verification by repeated observation and experiment, while its reasonings and predictions are based entirely upon the unvarying sequence of the phenomena of nature, as they display themselves before us.

Science is just as one and inseparable as life, or as an organic being, and its divisions no more imply lack of unity than do the various organs and limbs of an animal, or a tree, or the different structural parts of a building. Astronomy is not entirely independent of geology, nor geology of botany, nor botany of chemistry, nor any of these of physics, nor physics of electricity and magnetism, nor the last of physiology and medicine. Accordingly the question where to begin in studying science is not one that can be answered in the same way for everybody. But the spirit is the same in all the branches.

Perhaps the best general indication of the order in which a person who has no predilection for any one branch of science should take up the various parts is afforded by their historic development. This was a result of the natural reaction of man's mind to its surroundings. The things nearest to him, and most immediately important, first attracted his attention. The broadest division would be into the science of things on the earth's surface; the science of things above the earth, in the air and the sky; and the science of things within the earth, concealed from immediate view.

If we take these in their order they naturally subdivide themselves as follows:

1—THINGS ON THE EARTH—EXPLAINED BY

(a) Anthropology, the Science of Man and His Ancestors, treating of his nature, origin, development, division into races and tribes, society, industry, etc.

(b) Zoölogy, the Science of Animal Life, treating of the "lower animals," and of animal life in general as distinguished from the kingdom of the plants, although the related science of biology deals with both plants and animals, its special subject being the phenomena of life in its widest sense.

(c) Botany, the Science of Plant Life.

(d) Geography, combined with Physiography, the Science of the Face, or Superficies, of the Earth, dealing with lands and seas, rivers and mountains, political divisions, etc. This is covered in our series by the volume on Physiography.

(e) In this compartment several branches of science may be grouped, since they are all the product of study of things encountered on the earth's surface. They are:

Physics, the Science of the Forces of Nature, dealing with the laws of the inanimate world around us, including the phenomena relating to solid, liquid, and gaseous bodies and substances.

Chemistry, the Science of Matter and Its Changes, dealing with the atoms and their constituents, and with the combinations of atoms into molecules to form the various chemical elements, etc.

Electricity and *Magnetism*, the Science of Power, fundamentally underlying all other branches, and through its investigation of the nature of the constituents of atoms—the electrons—going deeper into the constitution of things than chemistry itself. In fact this science, in some respects, blends with chemistry, although it is quite separate when it deals with the mechanical developments of electromagnetism.

Medicine, the Science of Health, *Physiology*, the Science of the Body, *Psychology*, the Science of Human Behavior, *Mechanics*, the Science of Machinery, etc., also naturally fall into this category of Things on the Earth.

2—THINGS ABOVE THE EARTH—EXPLAINED BY

(a) Astronomy, the Science of the Heavenly Bodies.

(b) Meteorology, the Science of the Atmosphere, rains, winds, storms, fair and foul weather, the changes of the seasons, and essentially related to the new and fast developing art of aerial navigation.

3—THINGS WITHIN THE EARTH—EXPLAINED BY

(a) Geology, the Science of the Earth's Crust, or shell; which also deals with the various stratifications of the rocks, superposed one above another, and containing in the shape of fossils, and other marks, a wonderful record of the character and development of the living forms that have inhabited the earth during the long ages of the past. Of course some of the phenomena dealt with by geology are manifest on the earth's surface, and others, like volcanoes and earthquakes, hot springs and geysers, are partly subterranean and concealed from sight and partly evident by their effects on the surface.

(b) Closely associated with Geology are Mineralogy, the Science of the Constitution and Structure of Rocks and of Mineral and Metallic substances; Vulcanology, the Science of Volcanoes, and of earth disturbances in general; and the Science of Mining, which has several branches, and forms the basis of enormous industrial developments.

It is manifest, as before said, that the reader must be his own best judge as to the precise order in which to take up the perusal of the volumes in which this immense mass of scientific knowledge is presented. But, where there is no predisposition to choose one subject rather than another, or where there is a desire to follow, as nearly as may be, the natural line of development of human knowledge, it would be well to take first, after the history, the volume on astronomy, a science that from the beginning has had a peculiar power to awaken intellectual curiosity; then that on anthropology; then the various so-called "natural history" subjects, leaving the mechanical and the more technical subjects for the last.

Or, the reader might first take up the subjects of personal importance to every human being—Medicine, the Science of Health; Physiology, the Science of the Human Body; Psychology, the Science of the Mind—every one of which is essential to the proper care and preservation of life; and afterward study the other branches in the order already suggested.

Garrett P. Serviss

CHAPTER I

HISTORY OF SCIENCE

THE romantic history of science shows how the discoveries of the greatest human minds, slowly operating since the remotest times, have made possible our present-day civilization. Few studies are worthy of greater attention; no other department of knowledge affords more real pleasure. Whoever clearly understands the history of science possesses intellectual advantages over those who are ignorant of the causes that have led to the establishment of the basic principles of our modern industrial arts and applied sciences. Standards of comparison are furnished by the history of science which illuminate many of the wonders of to-day, develop alertness of mind, and afford a never-ending train of suggestions for thought.

The term science means knowledge. It was derived from the language of the Romans. It is well to have a clear idea of the meaning of the word. Everyone knows that it has to do with certain kinds of knowledge; few know the particular kinds it embraces. It does not mean the mere knowledge of a single fact. It does not mean a knowledge of something which has to be done. Long before science was born, our early ancestors observed many isolated physical, philosophical, and religious facts. They knew that day followed night, that the stars moved, that every day the sun progressed over the arch of the heavens. Such facts did not constitute science.

What we know as science began when man commenced to compare one fact with another, to classify phenomena, and to arrange his knowledge systematically. Order, method, system, are basic principles of science. The best description would, therefore, appear to be systematized knowledge of any kind which had been gained and verified by exact observation and correct thinking. The whole field of human knowledge is now methodically formulated and arranged into rational systems. Modern science may, therefore, be said to embrace all our exact knowledge. Its province is enormous; its subdivisions are limitless.

Science takes no account of knowledge which is not exact. Many people acquire valuable information which they profitably use in business, but which they are unable to communicate or describe to others because they do not actually understand it.

Farmers and flower growers often possess important practical knowledge of facts which are embraced by the principles of the sciences of agriculture, botany, and biology. But their practical knowledge is not true science. It is rather like an artist's intuitive impulse. It is not the result of scientific analysis, and there is no tangible, communicable residuum.

There could be no science if men did not discover principles of knowledge which can be communicated to, and made available for use by others. Scientific knowledge must be stripped of all traces of emotionalism and personal convictions. True science is, therefore, depersonalized knowledge.

The history of science shows how our exact knowledge has been developed along irregular paths but with progressive advances. There have been long periods during which little apparent progress was accomplished, which have been succeeded by others made memorable by brilliant discoveries.

We must constantly bear in mind that many of the truths generally accepted to-day were doubtful or novel theories at some previous period. The history of science shows the enormous mental effort expended in testing and developing what now appear to us as commonplace truths.

Basic principles like those of algebra, geometry, and the planetary motions were tested during several thousand years before they were finally accepted as true.

The human intellect at the dawn of history was similar to what it is to-day. But it was not exercised as we exercise ours because it did not have adequate materials and opportunities. For the same reason science made slower progress in early times than it does now. Progress is cumulative. Each advance helps that which follows. The functions of a scientist are to struggle against individual views, and to provide an explanation of phenomena which may be accepted as true by other minds. Ascertained facts must be classified and then sequence and significance recognized from an unbiased viewpoint.

The history of science is the written record of countless experiments, theories, and experiences of mankind which have been submitted to the tests of scientific methods.

While it is true that science embraces all knowledge its real scope is limited to knowledge which is reducible to laws and can be embodied in systems.

The human mind unites all knowledge by a single thread, but we have to chart and map it into larger and smaller divisions which we define by the methods, basic concepts, and plans used in developing them.

We may now see how it is that the boundaries of any science are merely approximate. The general grouping of the sciences is likewise approximate. The first large group includes the abstract, or formal, sciences such as mathematics and logic. The other great group comprises the concrete sciences dealing with phenomena as contrasted with formal relationships. Chemistry, biology, physics, psychology, and sociology belong to the concrete group.

At the beginning of history man is discovered observing the great phenomena of Nature and struggling to learn their laws and to explain them. Religion is both emotional and intellectual, and through these qualities it attracted primitive man while he was attempting to gather light on the riddles of the world. It was through religion that science was born.

Recent researches into primitive beliefs have shown in a surprising manner the psychological unity of man. In all parts of the world, in all periods of history, and under all conditions, the minds of men, in their natural reactions against the basic factors of existence, operate in similar ways. There is a remarkable resemblance in the mental processes of men. The laws of thought appear to work automatically in all men. The minds of prehistoric people worked like those of men to-day. The impressions of the senses appear to be interpreted in similar ways by all peoples. Here is the explanation of the numerous resemblances we find in national histories, national folk lore, and national religions. They differ much in innumerable details, but possess many resemblances in their great fundamental conceptions. Normal man has always been religious. Mankind has always assumed definite attitudes toward the universe and this has resulted in the universality of religion.

Early men the world over appear to have been as eager to learn the keys to the riddles of the universe as was the boy Longfellow sang about in the following stanzas:

Nature, the old nurse, took
The child upon her knee,
Saying: "Here is a story-book
Thy Father has written for thee."

"Come wander with me," she said,
"Into regions yet untrod;
And read what is still unread
In the manuscripts of God."

And he wandered away and away
With Nature, the dear old nurse,
Who sang to him night and day
The rhymes of the universe.

And whenever the way seemed long,
Or his heart began to fail,
She would sing a more wonderful song,
Or tell a more marvelous tale.

Modern science has developed from this instinctive human desire to read Nature's storybook and understand her marvelous tales.

Early struggles of mankind taught that human behavior must be regulated in accordance with rigid moral laws. This promoted the primitive social processes which were early concerned with religious beliefs as well as with magic and medicine. Two of the earliest beliefs universally accepted were that we possess souls and that our personality persists after death. These basic principles of faith have caused extremely beneficial results to follow in the development of knowledge.

Some of the American Indians and other primitive peoples of to-day still live in the belief that the heavenly bodies, the sky, sea, and earth, as well as plants, animals, and men, all belong to a vast system of all-conscious and interrelated life, in which the degrees of relationship are distinguished by the degrees of resemblance.

Religious beliefs were developed from struggles to conceive the inconceivable and discover the infinite. Religions led to studies of mysteries and ceremonies and rites. Magic developed and this also had its customs, dogmas, and rites. The difference between magic and religion was that the magician was consulted by his personal friends, whereas the holders of religious beliefs had a common bond uniting them in one strict form of worship. Magic was not systematized, while religion was a unified system of beliefs and practices relative to sacred things, and chiefly to the regulation of moral concepts and conduct.

The intimate association of religion, magic, necromancy, and science continued until the early Greek era. There were many temples erected in Greece and dedicated to Æsculapius, the god of medicine. Cures were believed to be effected through the valuable offerings made to the god by patients and their friends. It was thought that the ways to health would be indicated to them by the god through dreams.

Recent investigations of the representative ceremonial rites of the aboriginal peoples of Australasia and of North and South America have yielded a remarkably rich fund of information on the causes and conditions which operated in prehistoric eras in developing the mental, moral, and physical sciences.

Some of the most romantic stories ever developed by the human intellect are to be found in recent scientific works dealing with the history and principles of the tribal customs, ceremonies, and religious rites of primitive peoples. The early chapters in the history of man's mental development and the evolution of science from distant origins in mystic forces, through magic and necromancy to religion and philosophy, must give abundant pleasure to all thoughtful persons by showing how it came that the high state of civilization now attained was brought about by slow processes, operating through immense periods of time and blossoming only during the past two or three thousand years. A study of these stories cannot fail to show how intimately science has been associated with religion, why every normal individual is essentially religious, and why the continuation of our civilization, and the very existence of the human race, are absolutely contingent upon the recognition of the moral laws, in the future as in the past. The history of science establishes the fact that moral sanctions, which require religious ceremonies to keep them vital, are the essential bases of human progress.

CHAPTER II

PRIMITIVE MAN AND EARLY CIVILIZATIONS

THE development of scientific history has not followed a uniform course. Progress has been rhythmic. There has been always a reaction coming in the steps of brilliant discoveries. Periods of feverish experimental activities have been succeeded by others during which little apparent progress was made.

Such dull intervals seem to have been necessary for developing, formulating, classifying, and testing the innumerable details and inferences that the discoveries of the active periods produced.

While mankind in general has contributed to the total of our intellectual treasures, some races have been more active in this way than others. For this reason it is advisable to briefly survey the more recent discoveries about the ancestors of existing peoples.

Indo-Malaysia, parts of central Asia, and the valleys of the Tigris and Euphrates rivers in Mesopotamia are variously credited with having been the cradle of the human race. It should be understood, however, that we are only permitted to speak authoritatively of existing races, because the land forms of the earth have undergone such remarkable changes that we can know little definitely about the earlier periods of human history. For the purposes of the history of science, while bearing in mind these qualifying suggestions, we may accept the statement that man's ancestors originated in proximity to India.

It was around the waters of the Persian Gulf that the earliest known civilizations arose. The people who founded them came from central Asia. They had reached a considerable degree of culture, which suggests that they themselves came from earlier centers of civilization.

The study of prehistoric antiquity is termed archæology. Its principal periods have been divided, for convenience, into the Stone, Bronze, and Iron Ages. Each of these is distinguished by the substances used for tools. In the Stone Age men used stone spearheads, arrows, and knives, whereas in the Iron Age similar things were made of iron or copper.

The science of mankind is known as Anthropology. It deals with the innumerable steps in the evolution of mankind from remote periods, and with the primitive development of the arts, sciences, and religion. Yet it is one of the youngest of the sciences.

One of its essential teachings is that heredity and racial predispositions play, and always have played, more important parts in man's evolution, and in the development of civilization, than environment and education.

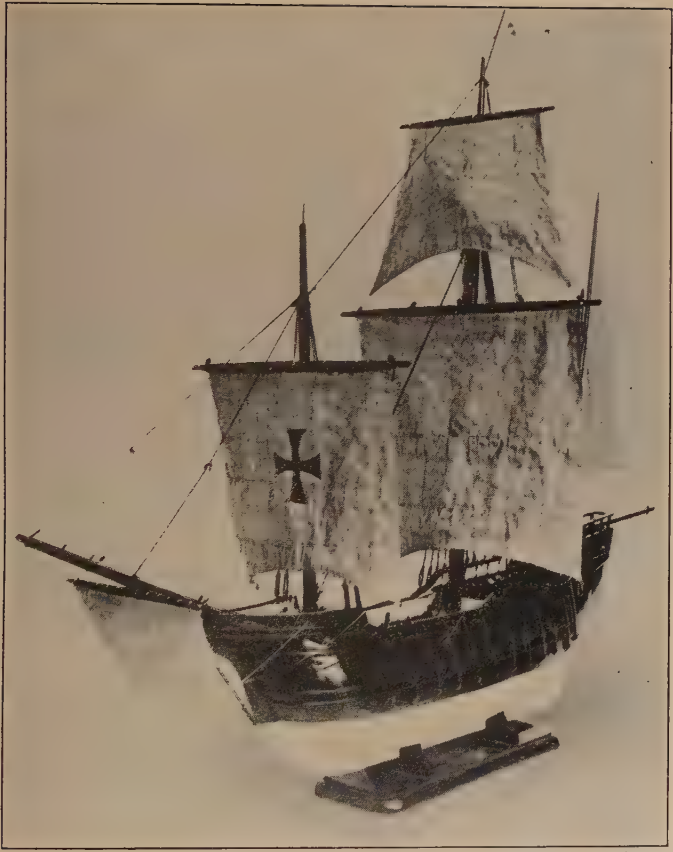
Hereditary tendencies, such as the religious, moral, and æsthetic instincts have been indispensable in preserving and developing all the races of mankind.

Moral discipline has been the chief factor in self-control, and therefore in civilization. It is because the moral sense has proved so beneficial to the human race, and is the most powerful of our instinctive desires, that mankind always has been and must be religious. It controls man's knowledge, desires, and will, and has dominated the race since our early ancestors began to think.

When we recognize this fact we can readily see that anything which tends to oppose the moral or ethical sanctions, or detract from religious beliefs, is injurious to civilization and human progress. The histories of religion, ethics, and æsthetics plainly develop the rôles which have been played by moral self-discipline in the protection and development of mankind, as well as of knowledge and science.

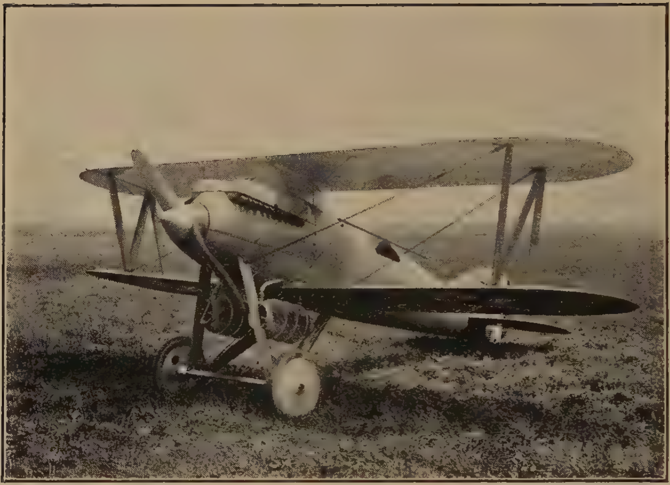
The moral control of individuals acts also upon society generally, and upon whole racial and national groups. The ethical ideals assist each individual mind to realize its own end and at the same time tend to influence the tribal and social mind to attain a common end. This great moral, instinctive force, which has played such an immensely valuable part in developing civilization and science, is known as the human social and national conscience. It acts both individually and collectively.

European races have been divided into classes corresponding to the prevailing cephalic indices. The longheads are grouped as the Nordic, or Baltic, subspecies, because they were formerly numerous around the Baltic countries. People of this group are distinguished by tall statures, fair skin and hair, good physique, and light colored eyes. These peoples include the Scandinavians, Anglo-Saxon, and certain important Teutonic groups, as well as Asiatic peoples who are known as the Aryans.



Copyright, Ewing Galloway

MODEL OF THE SAILING VESSEL "SANTA MARIA," THE FLAGSHIP OF COLUMBUS



CURTISS NAVY RACER, THE AIRPLANE THAT WON THE PULITZER RACE OF 1921

U. S. ARMY DIRIGIBLE ON A TRANSCONTINENTAL FLIGHT

The most important rôles in the development of modern civilization, art, industry, and science have been played by representatives of the Nordics.

The Iberian, or Mediterranean, subspecies, ranks next in importance. The peoples of this great racial division originally occupied the countries between the northern Atlantic coast of Africa and the confines of the areas of the Nordics around the northern provinces of France. They spread down the Mediterranean and over large areas in Asia. Their skulls are long, but differ from those of the Nordics in their absolute size. Their stature is lower, and weaker than that of the Nordics, while their hair, eyes, and skin are dark or black. The Welsh, the Moors, and the early Greeks are chiefly classed with the Mediterranean group. The Carthaginians, Phœnicians, Egyptians, and Etrurians were members of it.

The roundheads comprise the Alpine subspecies. This is the strongest numerical group to-day. It is characterized by small round heads, short bodies, dark hair, and dark eyes. It is of Asiatic origin and includes the Slavs, modern Greeks, Italians, Germans, Austrians, Swiss, the pre-Nordic Irish, French, and Belgians. The first Alpine invasion of Europe began about 10,000 B. C. There were many subsequent ones through the plateaus of Asia Minor, the Balkans, and valley of the Danube. They reached England about 1800 B. C., and formed small colonies in Ireland, the descendants of which now call themselves Celts and are clearly distinguished by the characteristic Alpine indices. This race is now so well acclimatized in Europe that most of its Asiatic traces have been lost, and its round skulls and dark eyes and hair are the only reminders of its Mongolian origin.

Members of each of these three great racial groups of mankind have throughout the ages contributed to the development of the sciences and arts. The Nordics began to appear in European history as agricultural tribes, speaking Aryan languages, like Celtic and Welsh, who swept down from the north and pushed the earlier settlers back through their irresistible arms, which were made of bronze and later of iron. The earlier settlers were still furnished with arms and implements of the Stone Age.

There was a much older intellectual people than the Nordics settled in Europe. The people of this race, about whom we have learned through recent archæological researches, are known as the Crô-Magnons. They lived between 25,000 and 10,000 B. C. Their skulls were distinguished from those of the Nordics by their prononunced cheek-bones and broad faces. Their culture, as their favorable cephalic index would suggest, was of a high character. Numerous drawings and art works of theirs, which have been preserved, place them among the world's superior peoples.

Soon after the settlement of the Crô-Magnons in Europe, and their intermarriage with the earlier settlers, their physical development and stature began to decline. They were finally absorbed and destroyed by the inferior peoples among whom they dwelled. Their disappearance, like that of the ancient Greeks, who appear to have been the most intellectual people the world ever produced, shows how the upward development of human physical and intellectual qualities is constantly injured by the contacts of superior and inferior races.

The scientific discoveries made prior to the Iron Age, or about 2000 B. C., were not numerous. The struggle for life was so intense that few had opportunity for contemplation and philosophic reflection. It was subsequent to the discovery of the basic principles of metallurgy, in the Iron Age, that science began rapidly to advance. The benefits bestowed upon mankind by the employment of metals reduced the sharpness of life's struggles, permitted and instigated reflection, and provided means for experimentation.

Modern history begins with the peoples of Mesopotamia. There were cultured peoples east of the Tigris and Euphrates, in Persia, India, Mongolia, Tartary, and China before the founding of Babylon. But we are more instructed about the Babylonians and Assyrians than about earlier Asiatic races.

The Babylonians and Assyrians appear to have originated in central Asia and to have migrated to Arabia about 10,000 B. C., and perhaps earlier. They were well settled in Arabia before the Egyptian pyramids and other Semitic memorials were planned. They brought with them from the farthest Orient many important contributions to civilization and culture, and developed many others.

These were religious, philosophical and keen commercial peoples. They shaped the organization of modern religions. The Babylonians reduced the world of gods to a single system with classifications distinguishing between major and minor deities, and between those of heavenly, or stellar, and earthly habitats, and those of time and space. They developed many religious myths of the Creation, the Flood, Paradise, and others which were subsequently embraced by other religions.

Both the Babylonians and Assyrians composed beautiful hymns, prayers, parables, and religious tales, and had numerous elaborate religious customs, rituals, ceremonies, and festivals conducted by priests, nuns, and acolytes.

Anu, or Anum, the God of Heaven, was the principal Babylonian deity, while Ashur was the leading god of the Assyrians.

Religious studies and rites occupied a large portion of the time of these peoples and, consequently, their temples, monasteries, schools, and other religious buildings were large and numerous. Their architecture was elaborately artistic. This was one of their incentives to scientific invention. They made important discoveries in all the basic physical sciences, like chemistry, physics, metallurgy, and mathematics, to enable them to improve their buildings and to embellish them with paintings, pictorial tiles, and fancy metals and textiles. They had excellent professional men, artists, jurists, bankers, contractors, and scientists. They were fond of literature and founded extensive libraries. Music and musical instruments were very popular with them. Their cuneiform writings, as disclosed by numerous beautiful stone and porcelain tablets which have come down to us, were excellently done.

The fragments of literature, laws, and religious policies that we are acquainted with indicate that the numerous Babylonian and Assyrian settlements in each great empire possessed social and political conditions similar to those of our days. Science and art were then sufficiently advanced to enable these ancient people to live as agreeable, moral, and legally secure lives as those of any subsequent peoples.

The Chinese appear to have been making similar progress to that of the Babylonians about the same period. It would seem that both these peoples were in contact with a similar but earlier cultured race in central Asia. Although the early Chinese were a religious people, they appear to have been more philosophical than the Babylonians. This enabled them to make further progress in the abstract sciences. In subsequent years they made rapid strides in the physical sciences, as will be shown later.

The Egyptians came into prominence toward the end of the Babylonian and Assyrian empires, and for many centuries played a great rôle in developing civilization. The numerous benefits which they bestowed upon the world by their researches in science and art are not fully appreciated.

Early history pictures two great Asiatic races struggling for supremacy in India. They were the Aryans, a fair-skinned people, and the Dravidians, a colored people. The Aryans succeeded in displacing the Dravidians in the great plains, upon which they settled and developed large cities, important world commerce, and contributed great art works and scientific and philosophical discoveries to the world's stores. The Dravidians retired to the hill country, where their representatives still live.

The minds of the various Indian peoples have always been strongly philosophical. This led them to the development of numerous religious sects and philosophical systems, and they made important mathematical discoveries. While the scientific bent of the ancient Greeks was of a concrete nature, which tended toward geometrical proofs for scientific problems, that of the ancient peoples of India was toward numerical symbolism and arithmetical proofs. We find that when the Greeks were developing geometry the Indians were contributing to arithmetic and algebra.

The Chinese closely resembled the ancient Indians in the philosophical tendency of their minds; but, owing perhaps to the different conditions under which they lived, they were more concrete in their ideas. They also made progress in mathematics and developed medicine, chemistry, metallurgy, and many of the sciences which were applied to commercial and industrial uses. The progress made in mathematics in China was transmitted to Egypt, and therefore to Europe, through India. Among early Chinese discoveries in mathematics were methods of solving numerical equations and the development of magic squares and circles, which gave a great stimulus to studies in geometry and astronomy.

The Arabs, Greeks, and Romans took up the discoveries of the Asiatic peoples, and the Egyptians enlarged them and passed them forward to us. The Arabs solved cubic equations by geometrical means, perfected the basic principles of trigonometry, and made great advances in mathematics, physics, chemistry, and astronomy.

A survey of the early history of science indicates that from the remotest period man was engaged in grappling with the great principle of causation. Progress was necessarily slow at first on account of the scarcity of tested data. Then it became more rapid. Soon after the founding of the great city of Babylon we find that the Babylonians were possessed of enough knowledge of the arts and sciences to enable them to become world traders and great industrial undertakers. They built many cities and lived highly civilized lives. The history of modern science may very properly be dated from the building of Babylon.

CHAPTER III

PRE-BABYLONIAN SCIENCE

THE transcending wonders of the phenomena of the heavenly bodies attracted the attention of primitive man at an early period of his intellectual development, The succession of day and night, the phases of the moon, comets, meteorites, the eclipses of sun and moon, the recurrence of the seasons were observed and recorded. In this way, through long uncivilized times, many scientific facts were noticed and handed down by tradition, and probably were among the first scientific data collected. We have no means of determining when the primitive science of astronomy became systematized, although there are reasons for believing that it was roughly outlined at a remote date.

There was a tradition among the Babylonian priests that their astronomical observations and records went back to a period of more than 400,000 years. This statement was believed by the people of antiquity, and was made to Alexander the Great during his Indian campaign.

Astronomy appears to have been developed into an organized system by the primitive peoples of central Asia. It was carried to China, India, and Arabia by learned travelers. There were government astronomers in China before the year 3000 B. C., and history records that two of these officials, named Ho and Hi, were beheaded in the year 2159

B. C. for being careless in their work and failing to issue a timely prediction of a solar eclipse.

Chinese history also relates that the Emperor, in 2857 B. C., issued an edict recommending the study of astronomy. From these and other historical references we learn that nearly 5,000 years ago astronomical science was not only well developed, but that its educational value was recognized.

While attention was being given to the study of astronomy in China, this science was independently developed in India. The astronomers of India invented a different system from that of the Chinese, and compiled numerous astronomical tables which were published and widely used as far back as 3102 B. C.

These early astronomical studies resulted in the division of time practically as we know it to-day. The Babylonians had a week of seven days. The days bore names of the planets and were divided into hours and minutes. Days were combined into months and years. The Babylonian and Chaldean astronomers, like those of China and India, were important men and were credited with great learning.

The Babylonian month began on the evening when a new moon was first observed. An adjustment was made necessary between the months, owing to the fact that the actual lunar interval is about twenty-nine and a fraction days. Numerous astrological observations were made with the view of obtaining data to facilitate the monthly adjustments. The taking of these observations was made easier by maps of the heavens which were recorded on baked clay tablets and prisms. Similar maps of the world, with positions fixed by astronomical observations, were likewise made in Babylonian times.

The usefulness of astronomical observations and predictions led to the belief that they could be employed with advantage for wider purposes. The astrologers endeavored to deduce omens and forecast horoscopes. In order to facilitate their calculations, the astrologers invented calculating and time-dividing machines. Tablets from the royal library at Nineveh indicate that Chaldean astrologers possessed mechanisms which divided the hours of the day by mechanical means. These were forerunners of modern clocks and timepieces.

These early scientists represented the earth as a vast circular plain, intersected by high mountain ranges and surrounded by a large river, with other mountain chains which lost themselves in an infinite ocean. The heavenly vault was believed to be supported by the highest peaks of the outlying mountains. It was owing to the peculiar nature of this cosmogony that the pre-Babylonians and Babylonians were unable to develop a satisfactory mechanical view of the world. The world had to wait for an adequate mechanical theory before general knowledge could be advanced, so that men like Newton and Laplace could correct the errors of early theories and furnish a sound working hypothesis.

The advancement of science requires methodical observations and the use of the highest powers of the imagination. It is thinking in picturelike figures that supplies primitive reasoning. While pure reasoning deals with abstract, verbal images, the more concrete picture-thinking deals with object-images. The differences between thinkers and dreamers is chiefly in the way their minds act. But even thinkers are supplied with thought material by the elementary mental operation of picture-thought, dreams, or dream-thinking. Science needs the active use of the imagination to anticipate experience and suggest the issues of a process in course of action. Most great inventions, and probably all primitive inventions, were stimulated by imagination. But the imagination, unless skillfully directed, is liable to numerous errors. That is why in all ages there has been much error in connection with knowledge. There could, however, be little or no progress without imaginative work. It is only within very recent years that the modern sciences have been stripped of much absurd matter derived from crude imaginative work. When we bear this in mind, we have the key to the part played by ancient myths, magic, and ceremonies in developing civilization.

The term magic is derived from the Persian term for priest. The magi, or priests of Zoroaster, their religion, learning, and occult practices had important world-wide effects just before the Babylonian era. Magic is a pioneer of religion, philosophy, and science.

Medicine was benefited, in some ways, by the priests seeking means for dealing with the work of the spirits of evil. Chemistry and metallurgy were also advanced, and new realms of knowledge were opened even by magicians.

The magic of the Babylonians survived their empire. It was handed over to the Egyptians and contemporary peoples, and was in turn passed down to the magicians and alchemists of the Middle Ages, and to the dramatists, poets, and novelists of all ages.

The accumulation of scientific facts was greatly facilitated by the improvements made by the Babylonians in the manufacture of earthenware tablets, scrolls, and prisms. Beautifully drawn cuneiform picture signs recorded on these all the knowledge of the day. These stonelike records were filed away in many monasteries and libraries. Subsequently, letters were invented, alphabets were formed, and writing displaced the hieroglyphic symbols.

The invention of alphabets made reading easier. This resulted in giving an impetus to education which has had cumulative effects right down through the ages.

We are now in a position to realize why scientific discoveries were made very slowly, and at long intervals apart, in early times. Facts had to be accumulated, studied, grouped, and compared. Accounts of these studies had to be pictured and stored away for future use. Only exceptionally learned men did this. But when alphabets were invented and education increased, numerous minds became active and there was a great extension of thought, experimentation, and philosophical contemplation. This was followed by the establishment of new religious houses, schools, and philosophical academies, at all of which the ablest men of the day emulated the scholars in formulating theories and making inventions.

Soon after the perfecting of cuneiform writing in Babylon, characters were devised for representing numbers. A vertical, arrowlike wedge represented the figure 1, while a horizontal wedge stood for 10. A vertical and horizontal wedge, placed together, signified 100. Other arrangements of these characters meant that they were to be multiplied, subtracted, divided, or added together. In this simple manner all kinds of arithmetical results could be recorded.

The Babylonian mathematicians were familiar with decimals, integers, and fractions, and their tables and records of astronomical and engineering calculations reveal a remarkably high degree of mathematical ability, indicating that peoples who preceded us by several thousands of years were familiar with the more important calculations requisite in trade and industry as well as for astrological computations.

Babylon was a great world metropolis. It occupied a position similar to that occupied by London to-day. Its merchants were engaged in world-wide commercial operations which needed good systems of bookkeeping and accountancy. These, in turn, presupposed a highly developed arithmetical system. Practically all the arithmetical calculations used in commerce to-day were employed by them. Their accountants, like those of China to-day, used the abacus, or calculating machine.

A lucid illustration of the accuracy of ancient calculations, the efficiency of their reports, and the confidence with which they executed intellectual duties is afforded by the following translation of a Babylonian astronomer's official report:

"To the King, my lord, thy faithful servant, Mar-Istar.

". . . On the first day, as the new moon's day of the month of Thammuz declined, the moon again became visible over the planet Mercury, as I previously had predicted that it would to my master the King. My calculations were accurate."

The records of Babylon furnish us with a wealth of documents of this character.

The numerous peoples of India have always been divided into castes. This has resulted in the pioneering work in science falling to the priests. However, the principal priests were among the most intellectual men of each generation and, as they traveled in search of instruction, India was always in contact with the progress made in China, central Asia, and Babylonia. These great centers of ancient learning progressed together.

The Indians were able mathematicians and discovered and developed at an early period what is now known as "Arabic notation." In this work they were assisted by the Babylonians.

The Indians, like the Chinese and Babylonians, solved problems in interest, discounts, partnership, the summation of arithmetical and geometrical series, and determined number changes in combinations and permutations with ease. They were also proficient in algebra, the extraction of the roots of numbers, various classes of equations, and the principles of trigonometry.

The Chinese have always been good mathematicians. It is probably due to this fact that they have at all times been such able traders and bankers.

We are not so familiar with the works of Chinese mathematicians in pre-Babylonian times as we are with the Indian; but the references of contemporary writers indicate that the Chinese scientists were as able and active as their contemporaries.

We have remarked the high degree of perfection which was attained in the Babylonian era by scholars in science and mathematics. Similar perfection was attained in art, industry, law, and medicine. The wonderful law work that has come down to us under the name of the code of Hammurabi indicates not only the extensive progress which had been made in law, but incidentally through its references the progress of agriculture, industry, commerce, and business.

Many references in the Hammurabic code, written about 2300 B. C., show that the medical profession had attained considerable advance in Babylon. Surgeons were daring operators. They commonly performed operations for cataract. Many of the common major operations now performed by surgeons were also done by the ancients. They were experts at setting fractured bones. The physicians made effective use of drugs. Many drugs employed to-day were known to them.

The discoveries of the early oriental nations were collected and developed in Babylon. The entire fields of science, mathematics, geometry, agriculture, astronomy, philosophy, and art were focused in Babylon and handed down to the Egyptians and the Greeks. Much credit that is given to ancient Greece should be shared also by Babylon. It was from Babylon that Greece obtained the principles of its civilization, arts and sciences. Even Greek architecture and sculpture were originally derived from Babylon.

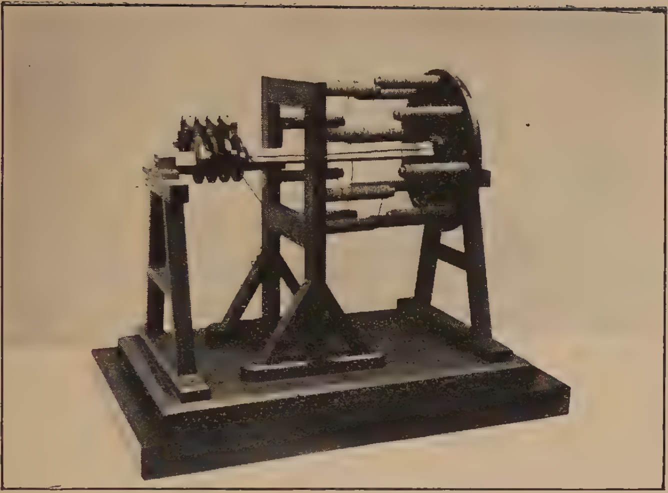
CHAPTER IV

EGYPTIAN SCIENCE

THE early civilization in Egypt developed in the ancient cities of Thebes and Memphis. Authorities on the dawn of history in Egypt are unable to definitely account for the origins of the various peoples who have ruled the land. One school contends that the early negroid inhabitants originated in Africa. Another school opposes this view and suggests an Asiatic origin. Each of these schools can marshal facts to sustain its contentions. The truth is that Africa was inhabited at such an early period that we are unable to fully trace back the movements of its races.

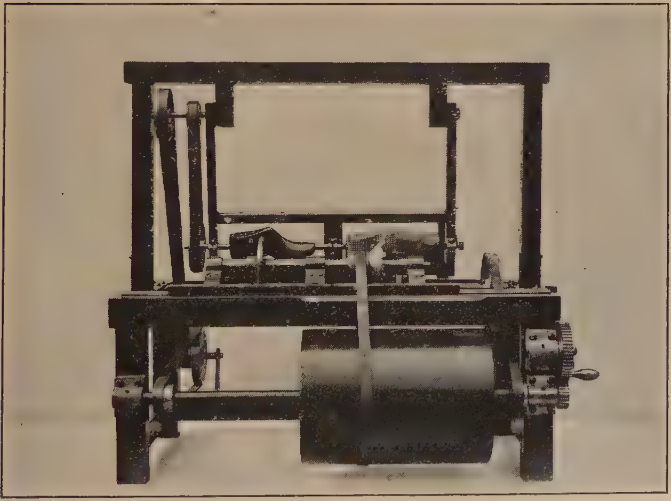
Man was divided into species and subspecies at a very remote period. The dominant peoples in each country, in each era, were the successful contestants in long conflicts for supremacy. Many races have vanished without leaving any traces beyond reversional strains which still come to the surface at times in families living to-day. The laws of evolution, only recently deciphered, are the sole means we possess for learning about many of the long-perished species of men.

A few races, too weak to ever gain supremacy and themselves to occupy districts, or countries, have survived by dwelling among stronger races. The Ainus, in Japan, and the Jews in Asia and Europe, are well-known examples.



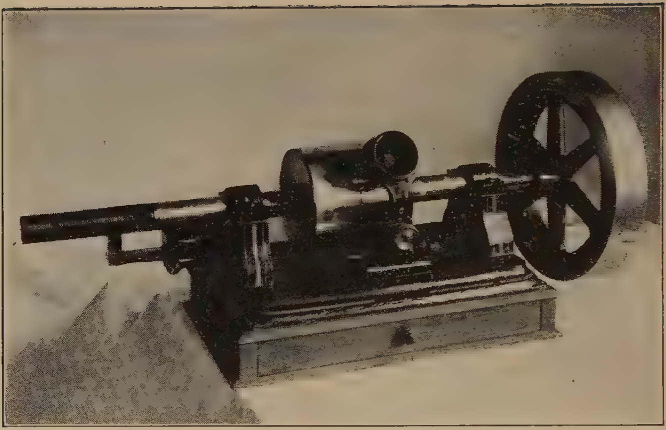
MODEL OF AN EARLY ELECTRIC MOTOR

The original was invented by M. H. Jacobi in 1834 and was used in 1838 to propel a boat on the Neva at St. Petersburg.



MODEL OF AN EARLY TURNING LATHE

This mechanism was invented by Thomas Blanchard in 1843. He also invented a lathe for turning gun barrels.



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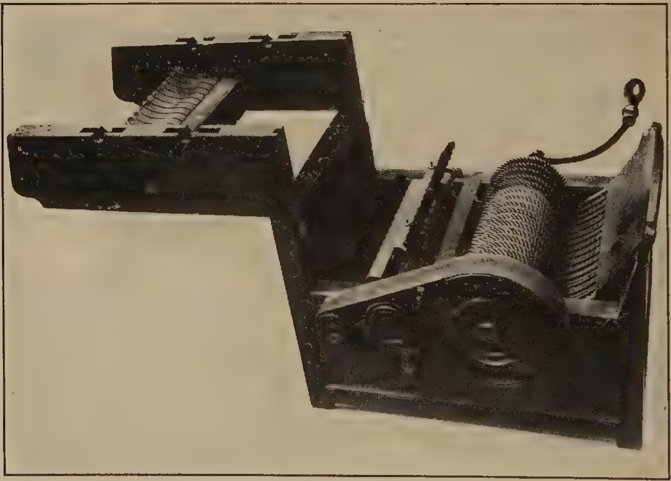
AN EDISON PHONOGRAPH OF 1878

The sound record was made on a sheet of tin foil vibrated by the voice



WHITNEY'S COTTON GIN

This device, invented in 1793, revolutionized the cotton and cotton manufacturing industries.

Egypt, owing to its remarkable geographical situation between Asia, Europe, and the vast continent of Africa, has been a great highway for race migrations. Many peoples have lived and ruled there and passed on before incoming tides of new and more vigorous peoples. Each race, undoubtedly, during its residence in Egypt contributed to the general fund of Egyptian knowledge and customs and assisted in the development of science.

The tombs of Thebes have given us bodies of ancient Egyptians of more than six thousand years ago. At that time the people were characterized by the Grecian type of profile. They resembled the contemporary active peoples in India and Arabia and did not differ much from the Egyptians of our day. The incoming streams of people who settled in the Nile valley, both Asiatic and negroid, changed the appearance of the Egyptians at different times by intermarriage, but when their vigor waned and they were crowded out by other peoples, the Egyptians assumed their regular Semitic characteristics.

Egyptian history really begins with the old kingdom dynasties, about ten thousand years ago. The tombs of Abydos have furnished material for accounts of this early period. There were eight powerful kings in the first dynasty and all of them contributed to the advancement of civilization. Abydos, and later Memphis, were their principal cities. They ruled in great luxury and were patrons of the arts and sciences. The art works, sculptures, and carvings in ivory and ebony of this era speak in eloquent terms of the taste and high mental powers of the people. Modern museums are well supplied with relics of those times, which illustrate the degree of civilization attained by the Egyptians at the beginning of their history better than any written account.

The early Egyptians adopted the sciences, arts and customs of the Babylonians. With these as a basis the priests and learned men experimented and made many independent researches and discoveries.

The pyramids, erected near Cairo 3000 B. C., indicate the high degree of culture which the early Egyptians had attained. These renowned monuments to the kings were scientifically designed and constructed to exist for all time. In order to contribute to their usefulness, they were planned so as to exhibit correct geometrical forms and indicate the cardinal points of the compass and the positions of certain astronomical bodies. The details of their construction disclosed much mathematical, geometrical and physical knowledge, and their actual building called for not only an all-around mechanical skill but a high degree of engineering ability. They were constructed of various materials. Some large granite blocks were used in the outside walls and these were brought from the upper Nile. They were towed down the river on barges and were lifted into the positions in which they are found to-day. Various mortars and mortar mixtures were employed in binding the brickwork and masonry. These called for a good knowledge of chemistry and physics. The arches and sloping walls of some of the larger pyramids show how well the architects and engineers of the day knew their professions. With similar means in their possession, the best professional men of the present day would find it difficult to get such splendid results.

In the past few years, lapidaries and gem-workers have learned to cut stones and gems with steel disk-wheels, the cutting edges of which are furnished with carborundum or emery powder or insets of diamonds. The pyramid builders knew this method of sawing and cutting stones. They actually employed bronze saws set with diamonds to cut the huge blocks of granite, syenite, diorite, and basalt used in the construction of the pyramids. They also set the cutting ends of their rock drills with diamonds, and bored rocks as we do to-day with diamond core drills. The art of making these tools was afterward lost. Only within the past half-century have mechanical rock saws and diamond drills been reinvented. This brilliantly indicates the inventive ability of the engineers at the dawn of Egypt's history. The builders of the splendid monument of Rameses II in the Memnonium, at Thebes, which weighs 887 long tons, transported the huge stone by land from the quarries at E'Sooan, a distance of 138 miles. Such tasks appear never to have deterred early Egyptian engineers and architects. They were so sure of their ability to carry their great operations to satisfactory completion that they never hesitated in agreeing to the severest penalties for nonfulfillment of contract. Their cranes, levers, wedges, rock drills, pumps, air blowers and compressors, and building tools all showed how well mastered was their knowledge.

Their quarrying methods were similar to those used in the best practice to-day. When huge blocks and slabs of stone were needed the required dimensions were marked on the rock and channeled out. Metal wedges were forced into the channels and struck at once by a large number of hammers. The constant vibration, in time, broke off the stone with clean-cut surfaces. When these were to be carved into statuary or ornamental shapes it was often done at the quarries, so as to reduce transportation difficulties. Water transportation was used when possible. When the stone had to be moved over the desert sands it was lifted by cranes and set on sleds drawn by men or animals, or driven forward by levers, just as heavy steel machinery is moved by modern engineers.

The principle of the siphon was known to the Egyptians at an early period. It was employed daily in many homes for supplying water and for drawing off wine from barrels and tanks into domestic utensils. Its principal use, however, was in civil engineering works. Siphons were constructed on a large scale for furnishing water to villages, draining land for farming, and for irrigation purposes. They were built, in many known instances, for carrying large quantities of water, in high lifts, over hills.

Herodotus tells us that the science of geometry was discovered by the Egyptians as a result of the necessity for making annual surveys of the farming lands in the Nile valley.

When geometry was established as a practical science, land and astronomical surveying were simplified and many branches of mathematics were enlarged. The science of marine surveying was also developed and this led to a great improvement in map-making and in geography, in which the Egyptians became famous.

The skill attained by the Egyptians in land surveying required accurate surveying instruments. These were invented at an early period. The Greeks claim the invention of the theodolite and similar instruments, but Egyptian history shows that gnomons, surveying compasses, and levels were used by Egyptian surveyors long before the Greeks began to study the learning of Egypt.

Astronomical science made great progress in Egypt. The theory attributing to the sun the central place in our planetary system, now called the Copernican theory, was known and used in Egypt. They were familiar with the obliquity of the ecliptic, and knew that the Milky Way was an aggregation of numerous stars of various sizes. They understood that moonlight is simply the reflected light of the sun. The movements of comets, the positions of the principal stars and stellar constellations and other astronomical phenomena were studied and charted on astronomical maps or recorded and forecasted in astronomical tables.

The discoveries made by the Greek scientists naturally stimulated philosophical thought, which in turn reacted upon scientific experimentation and led to a broadening of the scope of general research work. We are dependent upon the pictorial records of early Egyptian times for descriptions of the instruments and machinery employed and these are not always clear. They indicate, however, that the Egyptians quickly learned the sciences developed by the Babylonians and other Oriental peoples and improved them. Their knowledge of astronomy, mathematics, geometry, chemistry, physics, medicine, and agriculture was extensive. The priests and learned men taught the pure sciences and constantly experimented; the engineers, architects, surveyors, and mechanics applied the sciences to the arts.

In one of the records of an early dynasty the father of a student sailing up the Nile to begin his studies in one of the leading scientific schools gave this advice: "Put thy heart into learning and love knowledge like a mother, for there is nothing that is so precious as learning."

The Mesopotamian peoples, as we saw in the last chapter, considered the stars and principal heavenly bodies as deities. The Egyptians did not do this, although they looked upon the heavens as the abode of all pious souls. Their astronomical knowledge at the time of the establishment of the New Empire at Thebes, about the year 1320 B. C., was remarkably extensive.

The Egyptians divided time in accordance with the course of the sun into periods of 365¼ days, and these were divided in accordance with the course of the moon into periods of about 29½ days. Thus the basis of the system of years and months used by us was perfectly understood by the Egyptians.

The science of medicine was developed at a very early period in Egyptian history. The various divisions of physicians, surgeons, pharmaceutists, veterinarians, and dentists organized by the Babylonians were retained by the Egyptians. Many names of distinguished practitioners have been handed down. Nevertheless, their anatomical knowledge remained poor, and there were many superstitious practices connected with medicine. The various medical manuals which have been preserved show that the Egyptian physicians studied diagnosis with modern thoroughness. They were aware that an exact knowledge of each disease, obtainable only by a complete study of the symptoms, was necessary before a correct treatment could be prescribed. When the magic and the superstitious dressings are abstracted from Egyptian medical works and prescriptions, we find that the broad principles were sound and efficient. They were developed along lines similar to those of modern times.

Mathematics attracted much attention in Egypt. The learning of Oriental countries on this subject was readily absorbed by the Egyptians. The Greek historians were so surprised at the efficiency of the Egyptians in this branch of knowledge that they almost unanimously asserted that the mathematical sciences originated in Egypt.

The pyramid base lines run in the direction of the four points of the compass, and were determined by correct astronomical methods. The astronomers and surveyors were skilled in trigonometry. Fractions were known to the Egyptians, who were taught in the schools of Babylon. The modern x, representing an unknown factor, was known to the Egyptians under the name of "hau."

Quadratic equations were employed by them. The problem of finding x and y, when $x^2+y^2=100$ and $x:y=1:\frac{3}{4}$, one of the earliest problems of this character known, was found in a papyrus at Kahun. The problem was stated as follows: "A given surface of, say, 100 units of area, shall be represented as the sum of two squares, whose sides are to each other as $1:\frac{3}{4}$."

The papyrus gave the working out of the solution. Many similar problems are given in mathematical works and papyri. They show the proficiency in mathematics that Egyptian scientists had attained at a remote period. But their methods of expressing mathematical problems were crude and, consequently, involved much tedious labor in finding solutions. There can be little doubt that if effective mathematical symbols had been devised the abstract sciences would have made even greater progress than they did in early Egypt. When we study the complicated solutions of algebraic problems made by the Egyptians, owing to the lack of simple symbols, we can appreciate how greatly modern mathematical science is benefited by the devices now employed for expressing quantities, variations, and operations.

The Egyptians were expert in applying the discoveries of science to the arts. The Nile made their country potentially rich in agriculture, and they devoted much attention to inventing such things as single and double plows, rakes, and other agricultural machines, many of which were drawn by oxen, donkeys, and other animals. Reaping was done with sickles and scythes. Not only was irrigation understood and widely practiced, but the importance of fertilization was recognized.

The farmers understood the preservation of meat, vegetables, and foodstuffs generally, by drying or pickling. They also brewed beer and made wines, vegetable and seed oils, and alcohol. The selection of breeding animals and the principles of variation were understood and employed for developing particular breeds of cattle and farm stocks.

The papyrus reed grew luxuriantly in Egypt and this resulted in the discovery of paper making, weaving, thread making and many textile methods. These industries led to the invention of looms, rope and twine twisting appliances, flax weaving and other machinery. The linens and cloths made by these machines have never been excelled.

Dyeing was developed with the textile industries. As the skies of Egypt are bright, the people in all ages have had a fondness for brilliant colors. The call for bright textile colors led to a considerable development in the chemistry of dyes and dyeing. Vegetable and mineral dyes were used. Dyes were not always applied to the whole pieces of goods, but stenciling and other methods of patterning were used. The highly organized artistic skill of the people demanded art-designed textiles and the manufacturers responded with beautiful and rich materials.

The fur and feather industries became important at an early period. The Egyptians were fond of beautiful ornamental skins like those of the panther or gazelle. Such skins were manufactured into numerous domestic articles, made into clothing or used as rugs, mats, and seat coverings.

Skins not valuable for art purposes were sent to the tanners to be converted into various kinds of leather. Tanning was highly developed, and the tanners turned out leathers which are to-day admired for their excellence. The tanners carried on their industries by chemical processes similar to those in use to-day.

The scarcity of wood in Egypt led to the invention of various substitutes. One common substitute was a kind of *papier maché*. This was manufactured out of linen, wood or vegetable pulp and various kinds of paste. When it was used for art work the molded forms were covered with lacquer or various kinds of stucco. Very beautiful objects were manufactured from these substances, which indicate that the artists possessed a wide practical knowledge of physical and chemical principles.

Chemical knowledge was also well shown in their manufacture of glass. They excelled in this industry. All kinds of glass were made and decorated by staining and glazing. The glassmakers were able to imitate precious stones in glass and their glass-bead and enamel work has never been excelled. Some modern chemists express the opinion that glass making was carried to a greater degree of perfection in Egypt than any modern nation has attained.

Egyptian porcelains were also finely executed. These were enameled, stained, and decorated in numerous ways. The colors, glazes, and art mediums employed by the artists in pottery and porcelain necessitated a wide chemical knowledge. Some of the pigments employed both in glass and porcelain ornamentation were made from metals. Their use required a knowledge of metallurgy. Metals like lead, nickel, manganese required fluxing and refining before they could be secured in a state sufficiently pure to be used as bases for colors. Not only did the artists know the value of many metallic oxides, but they understood how to secure the tints resulting from blending different oxides, and by acting upon metals with acids, just as they acted upon vegetable and metallic dyes with acids to get rare tones in linen dyeing.

Mordants were employed in dyeing cloths and these were acted upon by acids and alkalies to produce various colors. We are dependent upon the relics which have been preserved for our knowledge of the chemical and physical learning of the Egyptians. No chemical books of theirs have come down to us, and inferences must be drawn from the results seen.

In carrying out metallurgical operations, the Egyptians employed small blast furnaces and melting pots. Air was compressed by bellows and conducted into molten substances by pipes.

The methods of metal working, melting, rolling, forging, soldering, annealing, and chasing were similar to common methods in use in modern times.

The Egyptians were a practical people. They made wonderful progress in the industrial arts and learned enough of scientific principles to enable them to deal with much success with the mechanical, agricultural, astronomical, medicinal, and chemical problems encountered. But, like the Babylonians, Assyrians and other Oriental peoples, the Egyptians did not systematize their sciences. Their investigations were always carried out with practical objects in view, and when the objects were attained the experiments ceased. They never discovered a true scientific method. That was left to be done by another people who were long students of Egyptian science and who, taking all the learning of Egypt, worked out from it, as a basis, the principal sciences as we have them to-day. The Greeks took the torch of scientific progress from the Egyptians, organized learning, and passed it on to the Romans and other peoples in sound, effective and augmented forms.

The Greeks idealized and systematized scientific principles, whereas the Egyptians and earlier peoples rested content with the results they could obtain by their practical efforts. We will find that, throughout the history of science, progress has always been made by similar reactions between peoples possessing the one a practical, the other a philosophical genius.

CHAPTER V

FOUNDING OF SYSTEMATIC SCIENCE IN GREECE

THE world is indebted to the Greeks as much for science as for art and literature. The idealistic spirit of ancient Greece invested scientists as well as poets, artists, and thinkers generally. But the Greek scientists were students in the great schools of Egypt and brought much of their knowledge from that country. The greatest contributions made by Greece were in the nature of methods and analysis. They were led to these by the tendencies of the Greek mind to abstract thought and philosophical investigations. They soon recognized that science is knowledge gained by certain methods of abstraction. Data had to be systematically collected, digested, classified, and impartially studied. The results of such studies had to be assembled and expressed in the most useful forms. Progress had to be made by the trial and error method and the results of experiments tested by synthesis as well as analysis; by induction as well as deduction.

The Ionian philosophers were the first to break away from the mythological traditions surrounding the principles of Egyptian and Asiatic science. Thales of Miletus about the year 580 B. C. taught that there is an essence, force, or soul in all things. This universal principle of activity is superhuman.

Seeking to find of what the world is made, he arrived at the idea that water, or moisture, is the basic element. All matter, he said, is water in various forms and combinations. Here we see scientific knowledge sought with a definite aim and with unity of purpose. None of the earlier peoples had ever attempted to approach knowledge in this logical and fruitful manner.

When the learned Babylonians were asked what the earth was they simply said: "When the world was created, Marduk, the sun god, took Tiamat, or Chaos, and divided her. The sky was formed above and the earth below." And the Egyptians answered the question in a similar way by saying: "When the world was created, Shu tore the goddess Nuit from the arms of Keb, and now she hangs above him and he is the earth."

It was this kind of statement that Thales cast aside. He sought for more concrete definitions. Customary beliefs were not acceptable to him; his knowledge must be based on reason. Here we see the dawn of a new scientific spirit and the beginning of a new method of investigating knowledge. The world was introduced to a new field of intellectual activities.

The theory of Thales was studied by other Greek philosophers. But Anaximander, a friend of Thales, rejected it, and in its place suggested that there is one eternal, indestructible substance which constitutes the basis of matter. This was not water but an infinite eternal motion. Water is subjected to extremes of temperature. Under such conditions nothing could have been stable enough to constitute matter. A primary substance must be free from warring or antagonistic elements.

The world arose, said Anaximander, through the evolution of a substance subjected to temperature changes which developed from the eternal, boundless, basic element. A sphere of flame arose from this, as from an explosion, and assumed a rounded form with concentric divisions. As these rings became detached, the sun, moon, stars, and other heavenly bodies and the earth were formed. Aristotle tells us that, according to Anaximander's theory, the terrestrial region was at first moist; and, as the moisture was dried up by the sun, the portion that was evaporated produced the winds and the turnings of the sun and moon, the remaining portion becoming the sea. In time the sea, Anaximander held, would dry up. The heat, or fire, of the world would burn the whole of the cold moist element. Then the world would become a mixture of heat and cold like the boundless, primary element surrounding it, and by which it would be absorbed.

This theory of matter and the evolution of the world marks a notable advance over any previous scientific theory. It was well developed by numerous teachers of the Milesian philosophical school and has played a great rôle in intellectual history.

The daring nature of some of Anaximander's explanations of earthly organisms may be realized from a sketch of his views on the evolution of animals. He taught that living creatures arose from the moist element as it was evaporated by the sun. Man at first resembled a fish. All animals were developed in the moisture wrapped in a protecting cover or bark. As they advanced in age, they came out into a drier atmosphere and discarded their protective coats. Man was not an original creation, but resulted from the fusion of other species. Anaximander's reason for this statement was that the period of infancy of the human being is so long that had he been born that way originally he could not have survived. There must have been a slow development from ancient ancestors. This may be regarded as an anticipation of the Darwinian theory. Thus man's thoughts in succeeding ages have a rhythmic swing.

Anaximenes rejected some of Anaximander's ideas and furnished new ones to take their places. He was not so daring a thinker as his predecessor, and his theory of the world was not as interesting as Anaximander's. Many of his teachings, however, are accepted as sound to-day.

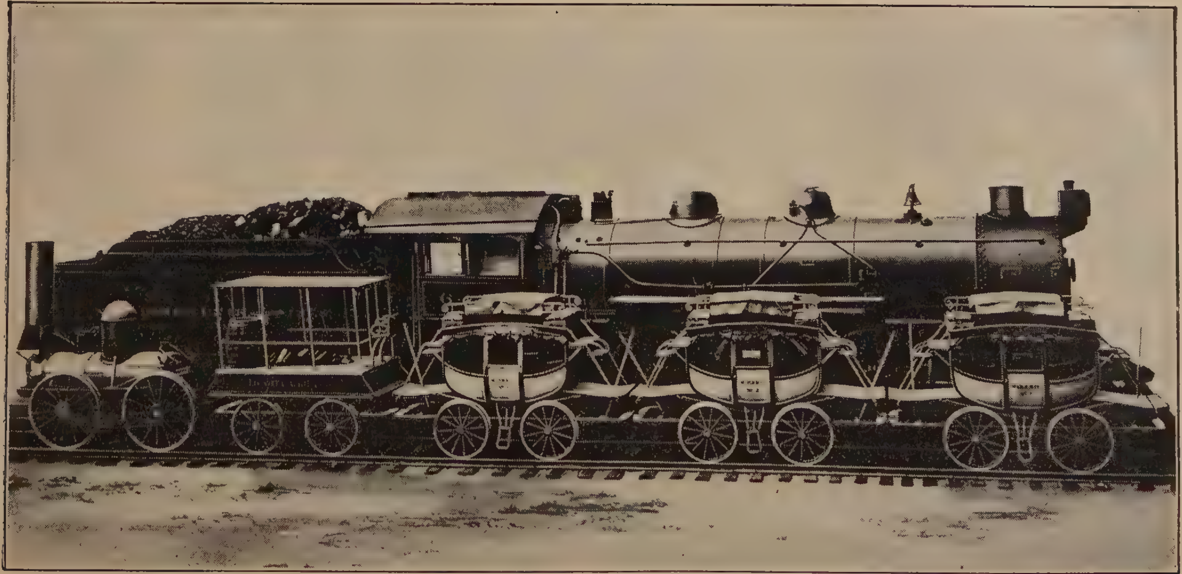
Anaximenes contended that the basic element was not boundless, but determinate. Innumerable substances are derivable from it and, just as our soul, like an atmosphere, holds us together, so do breath and air encompass the whole world. Air is always in motion, otherwise so many changes could not be made by it. It differs in various substances in virtue of its rarefaction and condensation.

The perpetual changes taking place in the world owing to the instability of matter were emphasized by Heraclitus. He taught that there is nothing immutable in the world process excepting the law or principle which governs it.

Cosmological speculations were not the only ones attracting the attention of the Greek scientists. Pythagoras, for example, founded a philosophical college devoted to mathematical studies which resulted in the development of arithmetic to points beyond the requirements of commerce. He made arithmetic the basis of a profound philosophical system.

Pythagoras studied science in Egypt and first became familiar with Egyptian and Babylonian mathematics and geometry. He also studied the Milesian cosmological philosophy. On his return to Greece from his foreign studies he sought to discover a principle of homogeneity in the universe more acceptable than any suggested by the earlier philosophers. He had noticed numerous relationships between numbers and natural phenomena, and believed that the true basis of philosophy was to be found in numbers. In seeking data to sustain this thesis, he discovered harmonic progression. His experiments showed that when harp strings of equal length were stretched by weights having the proportion of 1/2:2/3:3/4, they produced harmonic intervals of an octave, a fifth and a fourth apart. Since he saw that harmony of sounds depended upon proportion he concluded that order and beauty in the world originate in numbers. There are seven intervals in a musical scale, and seven planets sweeping the heavens. Seven must, therefore, be a basic number. This suggested to him his ideas regarding the harmony of the spheres.

Pythagoras and his students found that the sum of a series of odd numbers from 1 to $2n+1$ was always a complete square. When even numbers are added to the above series we get 2, 6, 12, 20, etc., in which every member can be broken into two factors differing from each other by unity. Thus $6 = 2.3$, $12 = 3.4$, $20 = 4.5$, etc. Such numbers were called heteromecic. Numbers like $\frac{n(n+1)}{2}$ were called triangular. A large number of other arithmetical relations were found and given distinctive names. The Pythagoreans were



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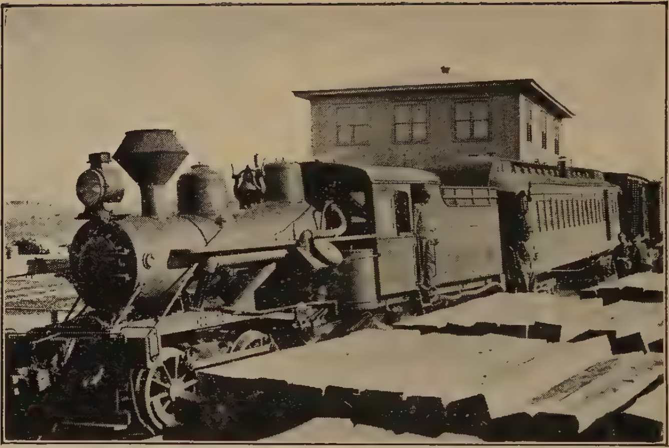
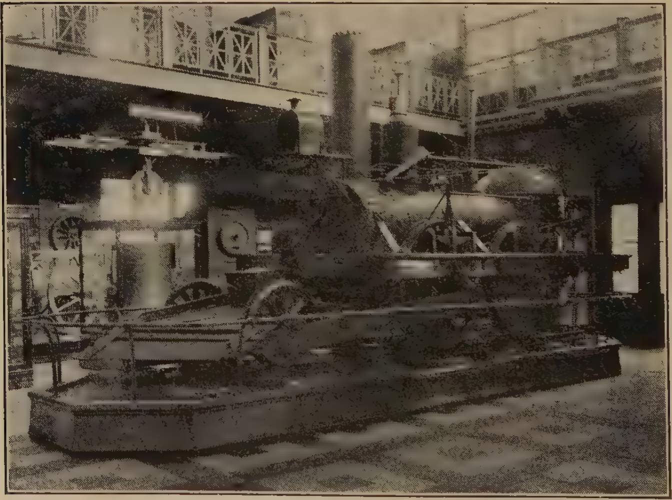


LOCOMOTIVE OF THE 1870 PERIOD STILL IN USE IN THE OZARKS



"JOHN BULL," A LOCOMOTIVE BROUGHT FROM ENGLAND AND PUT INTO SERVICE IN AMERICA IN 1831 also familiar with the principles of arithmetical, geometrical, harmonic, and musical proportion.

Pythagoras made similar advances in geometry. He believed that each arithmetical fact had an analogue in geometry, and each geometrical fact a counterpart in arithmetic. He devised a rule by which integral numbers could be found so that the sum of the squares of two of them equaled the square of the third. He also developed the theory of irrational quantities. The first incommensurable ratio discovered is said to have been that of the side of a square to its diagonal which is $1 : \sqrt{2}$

Euclid (300 B. C.) developed this theory in the tenth book of his geometry as still used.

Pythagoras not only placed mathematics on a solid scientific basis, he also established the fact that the physical phenomena of the world are governed by mathematical laws.

Little progress appears to have been made in astronomy by the Greeks in the time of Pythagoras. The Milesians and the associates of Pythagoras advanced numerous theories, but none of these was better than some of the Egyptian ideas. Hicetas, and others of this period, believed that the sun, moon, stars, and all other bodies in the heavens were stationary and that only the earth moved. The great turning movement of the earth around its axis produced the illusion that it was the heavenly bodies which were moving while the earth remained stationary.

The astronomical theories of Pythagoras, Hicetas, and Philolaus, all affirmed that the universe is composed of the elements earth, air, fire, and water, the whole mass being of spherical shape with the earth at the center and all having life or motion. These early theories, 2,000 years later, did service by aiding to secure acceptance for the Copernican theory. The Pythagorean ideas that the universe is one grand harmonious system, and that thought instead of sense is the sole criterion of truth, have exercised important influence on intellectual speculation throughout the ages.

In order to collect data for testing their theories in the physical and mathematical sciences, the Greeks invented many physical appliances. The monochord, employed in determining the relationships of vibrating harmonic strings is one of the first mechanisms used in practical physics that we have definite information about. An anvil, metal and glass disks, and bell-shaped cylinders were employed in studying the movements of sound waves.

Alcmæon (508 B. C.) was one of the earliest of the Greek anatomists. He was a disciple of Pythagoras and employed the logical research methods of his teacher in the investigation of medical problems. Although the Egyptians had developed medical science to a considerable extent and had taught the Greeks, their methods were not based upon sound principles. The result was that the more analytically minded Greeks could not accept certain Egyptian ideas. The Egyptian anatomical teachings were particularly crude, and Alcmæon began to investigate that science. His discoveries, both in anatomy and physiology, were very great. He outlined the functions of the principal organs of the body, discovered the optic nerve, the difference between the arterial and nervous systems, the Eustachian tube, the two divisions of the brain, the nerves connecting the brain with the organs of sense and with the spinal column. These advances placed the medical sciences on a logical basis similar to that of the physical, mathematical, and astronomical sciences. This first great anatomist and physiologist invented the practice of anatomical dissection and surgical exploration, and advanced the practice of medicine to a higher degree of usefulness.

After the Greeks had satisfied themselves that they possessed a cosmological theory which answered the demands of reason they turned their investigations to the question of how matter was changed into its innumerable forms. Empedocles had taught that when the primary elements, earth, air, fire, and water, were mixed in variable proportions they yielded different kinds of matter. Leucippus, Democritus, Anaxagoras, and others studied the subject more carefully and developed a novel theory. When matter is divided as far as possible do the ratios of the constituents remain the same? This problem attracted their attention. They also asked themselves whether there was not a simpler conception to explain the basic state of matter. When they began their inquiries, the qualities of matter were believed to reflect their essences. For example, the sweetness of honey and the color of the sky were real things which should be studied in themselves apart from honey and the sky. Democritus thought, however, that such changes of color as the sky undergoes at dawn and sunset would not take place if the colors were real elementary things. While meditating on this the thought arose in their mind: "If we assume matter to be composed of an infinite number of minutest particles or atoms, could we not explain the changes in matter by changes in atomic quantities and orders?" This line of thought resulted in the development of the atomic theory and the origin of the philosophic school of the atomists.

According to Leucippus some of the atoms darting about in the universe collide and thus give rise to new substances. He also believed that the atoms followed whirling or circular paths and that such rotary motions drew in neighboring atoms, and that as these movements continued indefinitely within the atoms the constituents were being constantly rearranged, the lighter elements being grouped around the periphery; the heavier ones around the center. These changes were due to pressure and impact. These conceptions about atoms were carried into cosmological discussions and it was taught that there are various worlds and planets within the boundless universe, each one moving freely according to physical laws, unless fractured by collision with another.

Zeno challenged these doctrines because of the importance attached to the whirling motion. He attempted to show that such atomic motions are impossible. His proofs of the impossibility of atomic motion were designed with the object of sustaining his own theory of an ultimate principle of unity. His mental trend was toward negation. Whenever his rival Parmenides argued affirmatively regarding a scientific principle, Zeno would invariably maintain the negative side of the question.

Zeno's first proof of the impossibility of motion referred to the impossibility of passing through a fixed space. He showed that by dividing a line into an infinite number of parts an infinite number of points would be obtained and these permitted no beginning of motion.

His second proof tried to show the impossibility of passing through space having movable boundaries. The story of Achilles and the tortoise illustrates this. A pursuer in a race at every interval must reach a point from which the pursued starts simultaneously. But the latter is always in advance.

The third, or "resting arrow," argument showed that a moving arrow is at every instant in some one point of its track. Its movement at such instant is then equal to zero. Its track is a group of zeros. No magnitude could be framed from these.

Zeno also anticipated much later philosophical discussions, like Einstein's, relating to the relativity of motion. He took for an example a moving wagon. Its movement would appear different to observers on other moving bodies going in various directions. They would see changes in rates of speed as well as in direction.

Protagoras, at a subsequent date, developed this idea of relativity and showed that things are as they appear to each individual at the moment they are perceived. He summarized his teaching in the aphorism: Man is the measure of all things.

The Skeptics, 200 years later, developed the Protagorean theory of relativity, and by a series of arguments attempted to prove that perceptions change not only with the different species of animate beings, but with many conditions and circumstances. It was also shown that not only man's perceptions are subject to changes, but also his opinions following from his perceptions. Another school taught that to every opinion the opposite can be opposed with equally good reasons.

CHAPTER VI

GOLDEN AGE OF GREEK SCIENCES

SCIENCE had made a great advance as a result of the researches and theories of the atomists. A consistent mechanical theory of matter and the universe had been set forth. Science and philosophy were stripped of many of the old superstitions that had clung to them. The leading theories invented were based on logical principles. While these changes were being worked out, numerous inventions of scientific instruments and apparatus were made and systematic methods of studying science were organized. These furnished the means for still greater progress.

The apparent completeness of the mechanical theory of the universe satisfied the inquiring intellect. The excitement caused by the scientific discussions and discoveries from the time of Heraclitus subsided. But after a short intervening period, when public attention had been largely centered on practical affairs, there was a reaction against science. When scientific principles were quoted a tendency was shown to question their validity and usefulness. This resulted in inquiries into the sources of knowledge and conduct and ushered in a new intellectual era that is now known as the Humanistic period which, beginning about 450 B. C., extended to 400 B. C.

The Sophists, who were teachers of rhetoric and were accustomed to studying the phrasing of verbal statements, became active in searching for the foundations of thought.

The Protagorean theory of knowledge was based on Empedocles's doctrine that the inner atoms advance to meet the outer ones. Perception is the resultant product of these atoms when they collide. They believed that this perception is something else than the perceiving subject and is also something different from the object giving birth to the perception. It is conditioned by both, but has a distinct existence. The doctrine of the subjectivity of sense perception was developed in explanation of this psychological problem. From this it followed that knowledge must be strictly personal and could be true only under conditions existing at the instant of perception. These limitations caused Protagoras to advance his theory of relativity, which teaches that man is the measure of all things. Facts are what appear to each individual to be statements of truth. Isocrates, Plato, Aristotle, and Socrates were the leaders of this intellectual movement.

Socrates developed the Pythagorean theory of intelligible forms. The specific qualities of the senses belong to the realm of perception. When these are withdrawn from an object of thought there remains only the form or idea. Therefore it is evident that pure, intelligible forms constitute the essences of things. The early scientists, such as Democritus, thought, perhaps, in terms of atom forms. Socrates, Plato, and later teachers looked upon forms as conceptions of similar logical elements. Knowledge, in the view of Democritus, was essentially rationalistic.

Plato considered knowledge as having ethical and æsthetic purposes within itself.

Each of these types of rationalism stimulated Greek thought and resulted in a strong impulse to philosophical and scientific investigation. They prepared the outlook for Aristotle.

Science had been hampered by the confusion raised by the discussions relating to forms. Aristotle realized that proper progress in logic, physics, and ethics, the leading sciences of his time, could not be made unless the essential nature of science were kept in view. He saw that knowledge of the forms of correct thinking can be understood only by keeping in view the object of thought and this requires definite ideas of the general relations of knowledge and its objects. The study of general relationships led to the study of particular or special relations. The connection of general with particular ideas was unfolded, and Aristotle saw that conceiving, understanding, and proving result from the deduction of particular from universal, or general, ideas. Therefore science consists in deriving or deducing facts acquired through perception from their general grounds or phenomena. The logical form of the syllogism naturally suggested itself to Aristotle when engaged with these thoughts and the invention of the syllogism was one of the most brilliant contributions to knowledge made by the Greeks.

The logical results of the invention of syllogistic forms suggested a solution of the problem of true reality which Aristotle showed was the essence that unfolds in phenomena themselves. This led to fruitful scientific results. Plato and his contemporaries unified mathematics, formulated the definitions logically, and demonstrated correct methods of criticism and proof. A point was shown to be the boundary of a line; while a line is the boundary of a surface, and a surface the boundary of a solid. This concrete definition of scientific elements progressed through the use of analytic methods, by proceeding from the known to the unknown, and led to the discovery of tests for scientific assumptions and of synthetic proof. None of the earlier philosophers possessed anything like the progressive tools Aristotle placed in the hands of scientists. Their use quickly led to a general review of knowledge and a great increase in the number of sciences.

The textbook on geometry compiled by Euclid, still used in many schools, gives us a good picture of the state of scientific methods in his time. Euclid, like Aristotle, Plato, Socrates and others, was a great systematizer. He collected the geometrical proofs of his mathematical predecessors, selected those which were logically correct and simple, and raised on a few axioms, or first principles, a great geometrical system.

Archimedes published textbooks on spherical and cylindrical geometry. He proved that the surface of a sphere is equal to four times a great circle. He showed the properties of spherical segments and methods for calculating surface areas and other parts of spherical forms.

This great scientist also developed mechanics and physics. He investigated the lever and demonstrated the principle upon which its power is based. He then studied hydrostatics and hydraulics, and discovered the theory of specific gravity and invented methods for determining it.

Apollonius began publishing scientific textbooks about forty years after Archimedes. His masterpiece was his textbook on conic sections.

The work done by Archimedes on the quadrature of curvilinear figures resulted, centuries later, in the discovery of the infinitesimal calculus, while the theory of conic sections published by Apollonius led to theories for the solution of problems relating to geometrical curves of all degrees. They placed the geometry of measurements and the geometry of forms and positions on strictly scientific bases.

Hipparchus applied the new mathematical and geometrical discoveries to astronomy. He found a method for representing the observed motions of the sun, moon, and planets by assumed uniform circular motions. His theory of the sun's motion assumed that the earth was not the center of the sun's orbit. He drew a line through the earth and the real center of the orbit and found where the sun's distance is least and where greatest. He then compiled a large set of solar tables giving the position of the sun among the stars at any time. He next turned his attention to the movements of the moon and prepared tables for determining eclipses.

Then the various planets were studied and their mean motions were calculated and recorded. The stars were mapped and catalogued. He described the apparent movements of 1,080 stars and comparing his observations and calculations with those of Aristyllus and Timocharis, made 150 years previously. He also discovered the precession of the equinoxes.

The astronomical calculations of Hipparchus led to a great improvement in trigonometrical methods. By using chords, as we use sinos, and assuming the heavens to be a plane surface, he fixed the positions of stars (and similarly geographical points) by the intersections of lines of latitude and longitude.

A planosphere, an instrument for representing the mechanism of the heavens, was among the many scientific inventions of Hipparchus.

While Hipparchus was engaged upon problems in astronomical physics, Hero, a professor of science at Alexandria, was working out numerous problems relating to matter and devising machines for practically applying the teachings of mechanical science. Ctesibius, assisted perhaps by his pupil Hero, made a large number of valuable engineering inventions. He was an authority on hydraulics and pneumatics. He devised improved siphons, a pneumatic organ, a force pump, a vacuum pump, a hot-air motor, and other machines.

His studies regarding the physics of gases led him to adopt a molecular theory of matter. He believed that there are vacua existing between the innumerable particles which constitute matter in all its states and forms.

Ctesibius improved surveying instruments. His dioptra, an instrument corresponding to a theodolite, was a plane table set on a tripod, furnished with compass points and two sights. The plane was adjusted by screws and a water level. This instrument was used by engineers for leveling, laying out irrigation works and farm lands, sinking shafts for mining and prospecting purposes, and for tunneling. A cyclometer for measuring angles of dip and elevation of rock beds and mountains was also used with this instrument.

The Greeks owed much of their knowledge of hydrostatics, mechanics, pneumatics, and physics generally to Ctesibius. He was not only a great inventor and lecturer, but also a writer of valuable textbooks dealing with physical and mechanical sciences.

Hero edited a number of editions of the textbooks of Ctesibius, and is credited with inventing some of the theories and machines discussed. He, too, published numerous scientific books.

Hero's work in trigonometry was important. He described a formula for estimating the area of a triangle which still bears his name. He defined spherical triangles and arranged methods for determining the volumes of irregular solids by measuring the water displaced by them.

The steam turbine is the best known of Hero's machines. Scholars read much about his wonderful musical instruments operated automatically by pneumatic means resembling the mechanisms of player-pianos, and particularly about his mechanical toy mimicking a number of singing birds. A group of birds were made alternately to sing and to whistle. The mechanism consisted of air tubes operating various kinds of whistles. A running stream was made to operate an air compressor. The air from the compressor tank operated the various movements of the birds and supplied air for blowing the whistles. The numerous mechanisms of this character which Hero and his master made indicate that they were as much at home in making pneumatic and similar mechanical toys as is any expert to-day. They not only knew the scientific principles, but had the engineering and mechanical ability to design them and make them work.

Hero's fire engine is not as well known as his steam engine. It was a remarkable invention, however. It was worked by levers and force pumps and resembled the engines still employed by fire companies in some remote rural districts.

Not the least interesting machine described by Hero was his slot machine for dispensing wine and other liquids. This machine consisted of a cylindrical container with a slot hole on top through which coins were dropped. Beneath this there was a lever with a receptacle for the dropped coin. The weight of a falling coin depressed one arm of the lever and raised the other, which opened a valve and allowed the liquid to escape. When the lever arm had moved a certain distance, the coin slipped off and the valve was automatically closed.

Hero's steam turbine was a crude model. Steam was generated in a boiler and conducted through pipes so as to play upon revolving globes or wheel vanes. This machine was invented to operate mechanical toys. It was not until nearly 2,000 years later that it occurred to an inventor that steam could be used to operate more important mechanism than toys.

The next great name in science is that of Claudius Ptolemy, an Egyptian astronomer, who lived in Alexandria about 139 A. D. He brought out new editions of the mathematical works of Hipparchus, and published a number of scientific books of his own. His principal work, known as the Grammar of Mathematics, formed the basis of all astronomical studies down to the time of Copernicus, about 1500 A. D.

The earth formed the center of the universe, according to Ptolemy's theory. The sun and planets, he thought, revolved around the earth.

We obtain our minutes and seconds from Ptolemy's great work. He divided the circle with 360 degrees and its diameter into 120 divisions. Each division of the circumference he divided into sixty parts. The Latin names for these parts were *partes minutæ primæ* and *secundæ*, or the first small divisions and the second small divisions.

The Greek scientists were so interested in logical analysis that they constantly investigated the fundamental facts upon which their teachings were based. They made provisional hypotheses, deduced mathematical consequences, and compared these with the results of observation and experiments. When Hipparchus found that his planetary theories did not meet his tests, he decided to make as many new observations as possible and collect astronomical data to be used at a later period by other scientists. He realized that, while he knew the old theories were incorrect, there was not enough data at hand to enable better theories to be established. He therefore deliberately labored to provide data for posterity.

Ptolemy's treatise on geography was an encyclopedia of places, names, and descriptions. In this work he located over 5,000 places between India and Morocco, giving their latitude and longitude.

Ptolemy's textbooks on sound and optics were long celebrated. The work on optics contained valuable chapters on refraction, a subject he had done much to develop. These works contained some of the finest collections of experimental data illustrating the best scientific methods used in antiquity.

The next great mathematicians and physicists are Pappus and Diophantus. The former lived about 300 A. D. He was the author of textbooks on mathematics and astronomy. Some of these have been preserved and are of great value in exhibiting the status of Greek science at that time.

The arithmetical textbook of Diophantus, which is extant, is remarkable as being the first to contain a complete exposition of algebra and the use of algebraic symbols and methods. Euclid solved quadratic equations geometrically and Hero solved them algebraically, although without using symbols. But in Diophantus's arithmetic quadratics are solved by the use of algebraic symbols. After several centuries, when the Euclidean geometry was in the ascendant, and many problems which were suited to arithmetical and algebraic methods of analysis were solved by geometrical and trigonometrical means, Diophantus succeeded in renewing interest in arithmetic and mathematics generally.

Political changes and other intellectual interests soon after the time of Diophantus turned men's thoughts in other directions and no great scientists were afterward developed by the Greeks.

While the physicists were making their discoveries, medical men were studying anatomy, biology, and materia medica. Medical science in the time of Diophantus had a status, with a theory and practice, closely resembling those of to-day.

Hippocrates of Cos (460 B. C.), was the greatest leader of Greek medical science. He cast superstition aside and based his researches and practice upon the same principles of inductive philosophy that had proved so valuable in other sciences. He established hospitals for the nursing of the sick, and had attendants note the symptoms and the histories of the cases. In this way a number of casebooks were made. He wrote a work on Public

Health. His operations in trepanning were more heroic than would be undertaken by good surgeons to-day. These are described in his book on Injuries of the Head. Many of his works are extant and furnish very interesting and valuable pictures of the state of medical science in Greece.

During the several centuries in which the Greeks placed science and all the leading departments of knowledge upon firm bases, stripped of the sentimental and traditional trappings which had come down from remote times, changes of a political nature were causing the immigration of foreign peoples to Greece. The importance of preserving racial purity was not recognized. The result was that the original Greeks, who were of the long-headed type, were forced to give way to the hordes of inferior peoples coming in from Asia. These new, round-headed people were not original thinkers, and were unable to advance science and the arts as the Greeks had done. They were, to a large extent, even unable to appreciate the wonderful treasures of knowledge bestowed upon them by the cultured people they had displaced.

The Egyptians and Babylonians advanced knowledge for practical purposes and when these were served they showed no desire to explore further. But the analytical mind of the Greek called for knowledge of basic laws and first principles.

CHAPTER VII

THE ROMAN AND MIDDLE AGES

THE Romans succeeded to Greek culture; but they were a business people. They exhibited smaller intellectual capacity than the Greeks for analytical thinking. This precluded them from advancing the sciences. The Romans attained great eminence in oratory, history, art, and literature. They probably equaled the Greeks in music. They never produced any great thinkers like Aristarchus, Hipparchus, Euclid, Ptolemy, Archimedes, Democritus, Hippocrates, Plato, Aristotle, and others referred to in the preceding chapters.

What the Romans lacked in intellect they made up in energy. They became good soldiers and sailors, good politicians, able architects, engineers, and farmers. This explains how they became so powerful politically. They were the most practical people in a practical world. Instead of bequeathing us great scientific masterpieces like the Greeks, they have left us miles of useful roads, waterways, walls, fortresses, bridges, buildings, and statuary. Remains of these objects occur throughout Europe and northern Africa, showing that Roman engineering practice has been as universally useful as Roman law and political practices. The great scientific discoveries of the world have been made by only a few peoples. Those nations which have possessed the scientific temperament have not always been productive. Great inventions and discoveries appear to be made in response to national needs and are preceded by long periods during which the preparatory work is being done. The great men of science being active generalizers, need the cooperation of many lesser scientists to collect data and observations upon which general theories may be built. This appears to be the explanation of the irregular periods of great scientific activity.

Julius Cæsar, great in many departments of human endeavor, carried through two important scientific reforms. He caused the rectification of the calendar. In the year 47 B. C. there was an accumulated error of nearly 85 days in the calendar. This was corrected and the year was made to consist of 365 days, with an additional day every four years. Cæsar's calendar is still in use.

His other reform, which was not completed until the reign of Augustus, was a scientific survey of the Roman empire. This conferred great benefits not only upon Rome, but upon the world. Geography, commerce, and industry were enlarged, many practical scientists were trained, and the various data and maps which had to be collected and drawn resulted in many improvements in statistical methods and in surveying and astronomical computations.

An early contribution to science by Rome was the textbook on Architecture by Vitruvius. This great work became the standard guide to building until the changed conditions in the Middle Ages called for new architectural methods.

The works on natural philosophy by Lucretius, the geography of Strabo, the books on natural history by Pliny, and the encyclopedic medical works of Galen were successive contributions. These chiefly aimed at developing the teachings of the great Greek scientists for the practical use of the Romans.

Roman history shows that all branches of the learned professions were popular and Roman professional men were very competent. None, however, stands out as a great discoverer. The names just above recorded are those of the chief lights of Roman science, and they simply reflect the practical nature of the Roman intellect. The best the Romans did was to preserve Greek science, test it extensively by practical applications throughout their vast empire, and hand it on to succeeding nations.

Philosophical thought in the declining years of Greece turned to theosophical speculations, and finally to ethics and theology. Much interest was evinced by the Romans in ethics, æsthetics, and theology. A new religion, destined to exert profound influences on intellectual developments, gradually attracted the attention of thinkers. The Romans were fascinated by the monotheism of Christianity and the doctrines of a future life and good will and love. There grew out of the critical attacks on this new theology a powerful scholastic philosophy aiming at the exposition, systematization, and demonstration of the principal Christian doctrines.

Aurelius Augustinus, a native of Africa (353-430 A. D.), championed the opinion that knowledge of God and self was the proper kind to study. The sciences have only value in illuminating the power of God. Intelligence is necessary to comprehend what we believe; faith is required to believe what we comprehend. As the highest good, or moral ideal, is transcendent, Christians cannot realize it, so human perfection should consist in the love of God and bearing good will to others.

The conditions brought about by this turn of thought were not favorable for scientific development. The world had to wait until the scholastic philosophy lost itself in metaphysical discussions. Then Roger Bacon (1214-1294) released science and mathematics from the chains which had so long confined them.

While European thought was occupied in discussing scholastic philosophy, the Arabs and Moors were carrying on the practice of the sciences. The Moors in Spain published many valuable textbooks and developed new principles in architecture and medicine. Their Giralda observatory in Seville was the first astronomical building erected in Europe, and their university in Cordova remained for a long period the leading professional school.

The universities of Paris, Salerno, Oxford, and Cambridge, and the law school at Bologna, were founded in the eleventh and twelfth centuries and have continued to hold up the torch of science until our time.

Roger Bacon, an English Franciscan monk, was a graduate of the University of Paris. He was a brilliant student of physical and mathematical sciences. Pope Clement IV invited him to write a textbook of science. Bacon did this in 1266. He became a professor in Oxford University in 1268. His *Opus Majus* (1267) summarized ancient and current philosophy and science and included the researches of the Moors. This great book reasserted the fact that science must be based upon experiments and that the astronomical and physical sciences must rest upon geometry and mathematics.

Bacon's clear recognition of the value of experimental methods and logical exposition mark him as the greatest intellectual force of his century.

The errors in the calendar were estimated and corrected by Bacon. He criticized the astronomical principles of Ptolemy, which were still generally accepted. His experiments in physics led him to make important discoveries in optics. He improved lenses and apparently made microscopes and telescopes. He proposed a lunar theory in accounting for the movements of the tides.

Roger Bacon made so many accurate comments on physical phenomena and so accurately forecasted recent mechanical inventions that his book, which was so far in advance of his time that it was unintelligible and caused him to be charged with witchcraft, still astonishes its readers.

Lenses were used for spectacles in Asia in the remotest times, but there are reasons for believing that Bacon was the first to prescribe them on scientific principles for the correction of defective vision. He also appears to have appreciated the value of gunpowder as an explosive agent and had it introduced into Europe from Morocco. Being misunderstood, Bacon founded no school and left no students.

Nicole Oresme, Bishop of Normandy (1323-1382), used fractional powers in mathematics and developed a notation. About the same period, Thomas Bradwardine, Archbishop of Canterbury, wrote on star polygons, and other Englishmen, like Boethius and Bath, wrote new textbooks on astronomy and mathematics. They started a school of trigonometry in England that made great improvements in that branch of science.

Between 1200 and 1400 A. D. the magnetic compass was improved and used at sea, clocks were improved and made popular, improvements were made in weaving, printing was invented, textbooks were written on many subjects, and education began to spread in Europe. All these factors prepared the way for a great industrial and scientific awakening.

Nicholas de Cusa (1401-1464), Bishop of Brixen, published books on mathematics and suggested that the earth's movements indicate a diurnal rotation.

The way was now paved for a new theory of planetary motions. Nicolaus Copernicus (1473-1543) a Pole, developed the astronomical system bearing his name, as a result of suggestions gained by studying the works of the Greek astronomer Hicetas, and Plutarch's Lives of Greek Scientists. His great work was entitled "De Revolutionibus Orbium Celestium, or the Movements of Heavenly Bodies," which treated the sun as the center of the planetary system.

Weather forecasting was improved by Tycho Brahe (1546-1601), and many fine astronomical observations were made by him. He greatly improved astronomical instruments and built and splendidly equipped a great observatory in Uraniborg, Denmark. Numerous important observations were made there.

John Kepler, the discoverer of the ellipticity of the planetary orbits and the laws of their movements, was a student under Brahe, and continued his master's researches. His observations on the movements of the planet Mars led to his discovery that the planets travel in ellipses and not in circles. Besides his numerous works on astronomy he wrote valuable books on optics and other scientific subjects.

Galileo (1564-1642) took up the work of Tycho Brahe and Kepler and carried it forward to new triumphs. He made the first telescope ever used for astronomical observation, and with it was able to discern that the Milky Way was composed of aggregations of innumerable stars; that the surface of the moon was covered with plains and mountains, that there were four moons revolving around the planet Jupiter, that the planet Venus showed phases like those of the moon as she moved around her orbit, and that there were black spots, at times, upon the sun, which revealed its rotation on its axis. Galileo did equally fundamental work in developing the laws of motion, and the principles of mechanism and physics.

The development of modern mathematics began with three intellectual feats—the invention of the Arabic notation, of decimal fractions, and of logarithms. The notation was derived by the Arabs from India about 700 A. D. They had used numerals long before, but the old system was crude like the systems employed by the Egyptians and Greeks. The Textbook on Mathematics by Mohammed ibn Musa, published at Bagdad about 825 A. D., contained the first notable exposition of modern numerals. This important work gave rise to many more Arabic treatises, some of which showed improved methods.

Decimal fractions were used by the early peoples of central Asia and were transmitted by them to the Babylonians. Their system was based, apparently, upon a sexagesimal scale. Simon Stevin (1548-1620), a Belgian, made great improvements in decimals. He adopted the plan of William Buckley, of England, and other mathematicians, and made the base 100,000, instead of 60.

John Napier (1550-1617), a Scottish nobleman, invented logarithms. The story of this great mathematician's work is one of the most interesting in the history of science. Napier's first table of logarithms was published in 1614. Henry Briggs (1556-1631), professor at Oxford, made suggestions for the improvement of the tables, and persuaded Napier to make the base 10, as is now done in tables of common logarithms. Briggs published tables in 1624 containing the logarithms to 14 places of decimals for the numbers between 1 and 20,000 and from 90,000 to 100,000. Adrian Vlacq (1600-1667), a Dutchman, computed the logarithms of the numbers running from 20,000 to 90,000, and thus completed the whole series of logarithms between 1 and 100,000. Edmund Gunter (1581-1626), of London, calculated the logarithmic sines and tangents of angles for every minute to seven places. He invented the terms cosine and cotangent and used them in a work published in 1620.

Another Englishman, William Oughtred (1574-1660), wrote textbooks on mathematics, and invented numerous mathematical symbols which are now in general use, as well as rectilinear and circular slide rules.

Bonaventura Cavalieri (1598-1647) made many improvements in mathematical formulæ and expounded a new method of indivisibles which solved some of the difficult astronomical problems raised by Kepler, and enabled Torricelli, Viviani, de Roberval, and others to solve abstruse problems relating to all types of curved figures.

Pierre de Fermat (1601-1665), one of the greatest of French mathematicians, developed rules for calculating maxima and minima. His functions in this type of equation closely approached those of the differential calculus. The calculus was developed from Fermat's work by Lagrange, Laplace, Fourier, and other Frenchmen.

Pascal and Fermat developed the theory of probability. Pascal worked out many useful methods for dealing with curves.

The intense mathematical activity in England and France resulting from the stimulation given by the invention of Napier, prepared the way for the discovery of the infinitesimal calculus by Newton and Leibnitz.

Newton was born in England the same year that Galileo died in Italy. His greatest work is presented in his celebrated "Principia," or "Mathematical Principles of Natural Philosophy," in which the law of gravitation, the laws of motion, and the mathematical principles of mechanics are developed. The "Principia" was published in 1687, and it has ever since been regarded as the corner stone of mathematical and physical science.

CHAPTER VIII

SCIENCE IN THE SEVENTEENTH CENTURY

THE wonderful advances made in the mathematical, physical, and astronomical sciences, and the invention of many new scientific instruments, together with the publication of improved textbooks and scientific tables, like those mentioned in the preceding chapter, stimulated interest in other fields of science at the beginning of the seventeenth century.

Medicine, which failed to advance with the astronomical and physical sciences, began to improve. The Moors had established great medical schools in Spain, but their teachings were based upon the principles enunciated by Hippocrates and the Greek schools.

Modern medicine was started upon a firm basis by John Harvey (1578-1657). Hippocrates taught that the blood was one of the principal parts of the body—one of the four great "humors." Its movements, however, had never been investigated until Harvey began to study the functions of the arterial system by the dissection of animals. The arteries had been considered as merely air tubes. This was due to the fact that they were studied only in postmortem examinations when they were empty. The anatomists of the sixteenth century failed to grasp their importance.

Harvey, who was a penetrating observer, had studied in several continental universities as well as in England, and having an original mind he determined to test the medical theories which he had been taught. His discoveries of the functions of the heart, the arteries, and the veins were epochal. He did his work so well and made such simple, yet telling, demonstrations that he had less difficulty than his predecessors in getting his teachings accepted. He was soon recognized as the peer of Hippocrates and Galen.

Harvey died without actually seeing the blood coursing from the arteries into the veins, but four years after his death Marcello Malpighi (1628-1694) exhibited microscopically the passage of blood corpuscles through the minute vessels in the lung of a turtle, on their way from the heart through the arteries into the veins and returning to the heart. The blood circulation was demonstrated at a subsequent date by applying a microscope to the web of a frog's foot. With low-powered lenses a good view is obtainable in this manner.

Many other important discoveries were made by Harvey, particularly in embryology. He demonstrated that the embryo chicken is formed by gradual development and processes of differentiation and not, as had previously been believed, from a minute perfect chicken.

Microbes were discovered in 1683 by Antonius von Leeuwenhoek (1632-1723), when he was examining some scrapings from his teeth. He saw for the first time the long and short rods of bacilli and bacteria, the spirillum and the micrococci. He tried means for destroying them and met with a fair degree of success with a gargle composed of a mixture of vinegar and hot coffee. This experiment was one of the early anticipations of antiseptic surgery, which was invented by Lister in the nineteenth century.

A French surgeon, Ambroise Paré (1517-1590) was a pioneer in the treatment of wounds. The old method was to use boiling oil. He found that by simply cleaning and bandaging wounds he could get better and quicker results than with hot oil, which was a very painful treatment. Paré used ligaments in stopping hemorrhages, improved the surgery in harelip and hernia operations and for suprapubic lithotomy. He learned the principles of these operations from Peter Franco (1505-1570), an itinerant surgeon, who had much skill in operations for kidney and bladder troubles.

Franz de la Boë (1614-1672), a professor in the university of Leyden, who is best known under the name of Sylvius, the discoverer of the brain fissure of Sylvius, founded a new school of chemical medicine. Van Helmont suggested to him the possibility of the stomach being the seat of many common disorders. When this was investigated, many experiments were made with new medicines. The success of these experiments led to a great reform in medical practice. Thomas Willis (1622-1675), an English physician, completed the development of the treatments suggested by Van Helmont and Sylvius as a result of their studies of the works of Harvey.

Another great English medical genius arose to establish the practice of medicine on a scientific basis. Thomas Sydenham (1624-1689) founded a school of medicine in accordance with these three principles: (1) Accurate descriptions of the courses of diseases, (2) following a fixed method of treatment in each disease, (3) searching for specific remedies for each diseased condition.

The results of these teachings were very pronounced. Before Sydenham's time, the only drug used in medicine was an extract of cinchona. The Dutchmen above named and Sydenham discovered many active medicinal substances. Sydenham's principal discovery in materia medica was that of the properties of laudanum.

William Gilbert, court physician to Queen Elizabeth of England, while Galileo and Stevin were developing the laws of gravitation and hydrodynamics, undertook the investigation of the laws of terrestrial magnetism and chemistry. His researches in chemistry were extensive and valuable. His fame, however, was perpetuated by his study of magnetism and electricity. He found that the earth is a vast magnet with north and south poles. His remarkable textbook on magnetism covered many of the fundamental facts known to-day. He noted the distinction between magnetism and electricity, described electrical charges, the principles of conductivity and methods for magnetizing iron. Galileo wrote of him: "I extremely admire and envy this author."

The mercurial barometer and its laws were discovered by Evangelista Torricelli (1608-1647) a student of Galileo. By means of his barometer, Torricelli was able to make great advances in knowledge relating to the physics of the air and to gas pressures, and he investigated the principles of hydraulics. The microscope, telescope, sextant and other instruments were greatly improved by him, and his mathematical work ranks only second to his contributions to experimental science.

The Torricellian tube, used as a barometer, was a means of creating a vacuum, which was formed at the top of the column of mercury. Pascal, the French mathematician, took up the study of the physics of the vacuum and published an important work on his own experiments. These and other experiments made by European scientists prepared the ground for, and suggested, the investigations of gases and vacua by Boyle, Mariotte, and others which finally resulted in the invention of the steam engine and many other modern machines.

Robert Boyle (1627-1691) published at Oxford in 1660 a book which distinguished between chemical compounds and chemical mixtures. He adopted the use of the term gas, which was first proposed by Van Helmont, and made some valuable studies on the physics of boiling and freezing. The oxidation of metals, the results of calcination, and of the fusing of metals and alloys, calculation of the atmospheric pressure, a study of colors as affected by light rays, and investigations in electricity were among the scientific works carried out by this great experimenter. But his fame rests mainly upon the results of his researches on gases.

Boyle began life as an alchemist and died a well-trained chemist.

Edme Mariotte, a French contemporary of Boyle's, carried out similar experiments and assisted in formulating the physical laws of gases bearing the names of Boyle and Mariotte.

A German physicist, Otto von Guericke (1602-1686), also followed up Boyle's work and invented a new form of air pump. He also carried on important experiments in electricity.

Gilbert, Harvey, Van Helmont, Torricelli, Boyle, Mariotte, and other similar pioneers in scientific methods not only invented numerous valuable instruments and wrote suggestive textbooks, but advanced scientific learning and the love of it by their delightful accounts of their experiments.

Modern education started with these men. Before this period there had been a sterile age in which the fundamental purpose of education was only to teach men how to protect the soul and to serve God. This humanistic principle, however, failed to advance knowledge of the laws of nature, and the researches of the scientists gradually caused a strong reaction against it. This in turn resulted in further advances being made, not only in the sciences, but in all departments of learning. The way was paved for the era of naturalism, developed by Hobbes, Locke, Descartes, Voltaire, Kant, Rousseau, and others. Naturalism aimed at explaining all phenomena in the simplest terms, and correlating all things by universal principles. It has received a great impetus in modern times from the Darwinian theory of evolution.

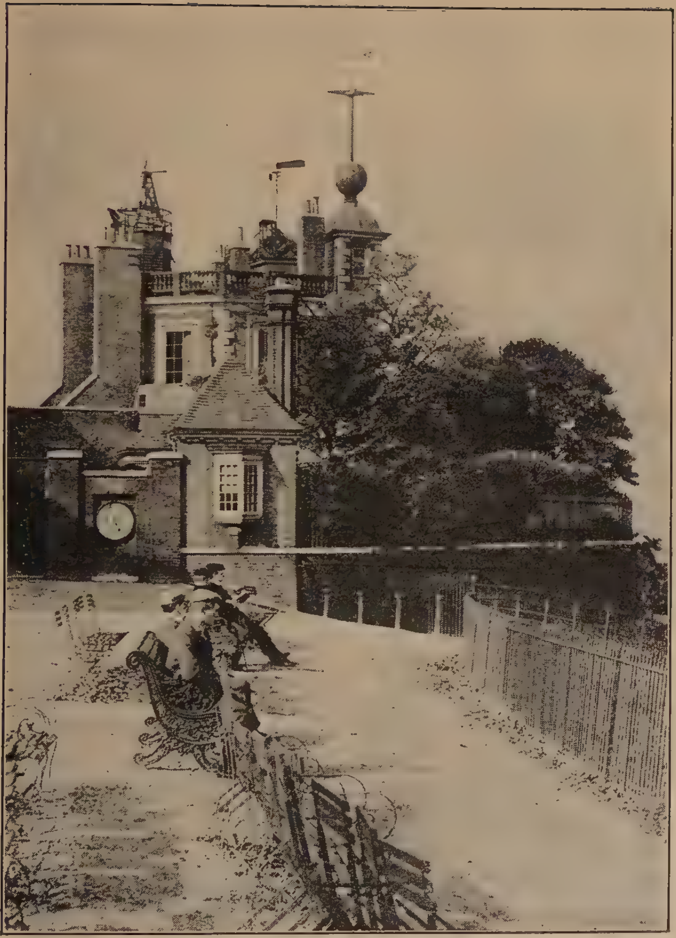
The great scientific discoveries of the sixteenth and seventeenth centuries had other important educational effects. They led to professional specialization and the founding of scientific institutions, schools, and universities. The Lyncean Society of Scientists was founded in Italy in Galileo's time. It subsequently became, in 1657, the Accademia del Cimento.

The Royal Society of England was organized about 1645 and chartered in 1662. It did much valuable scientific work from its inception. It has assisted the foremost scientists in their work, directed scientific researches, and financed the printing of scientific records and the carrying out of foreign expeditions. Nearly all the leading countries in the world have formed institutions with similar aims.

The chemical discoveries of Boyle attracted widespread attention and led to investigations started with the view of discovering the constitution of matter. Hermann Boerhaave (1668-1738) of Leyden, took up the study of organic chemistry. Stephen Hales (1677-1761) did similar work in England. Both of these chemists invented valuable laboratory processes and instruments. Hales improved the pneumatic trough used for collecting gases.

Scientists were now furnished with the telescope, compass, sextant, microscope, barometer, thermometer, air pump, manometer, and other instruments so that cellular structures of plants, animals, and insects, the microbes and bacteria, the animalculæ found in water and in the sea, as well as the phenomena of the air, sky, and earth crust could now be studied by trained observers. The invention of these instruments caused workers to specialize more and more, and completely severed science from philosophy, of which it had been an appendage since the earliest times.

The microscopical investigations of Malpighi, Kircher, Leeuwenhoek, Grew, and Hooke opened up an immense field for research. They developed microscopical chemistry and anatomy, and changed the prevailing ideas regarding animal and vegetable tissues. The sciences of mineralogy, botany and entomology were benefited and the medical sciences were practically revolutionized. The first publications of the Royal Society show the widespread



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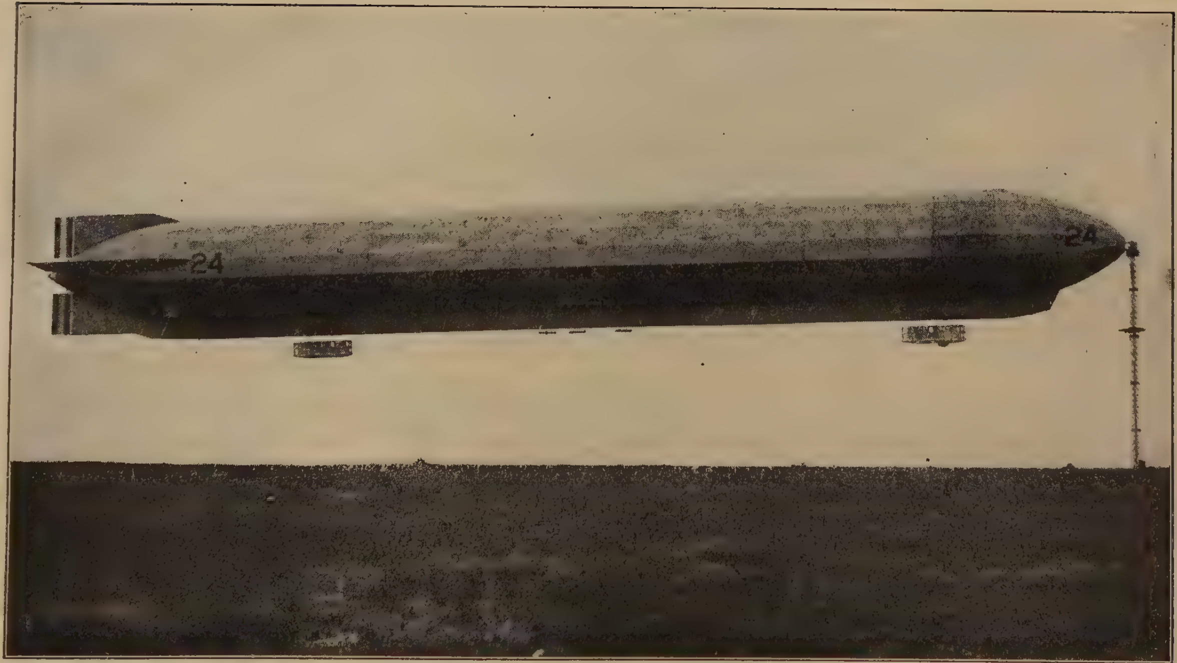
WEATHER AND ASTRONOMICAL INSTRUMENTS ON THE ROOF OF GREENWICH OBSERVATORY, ENGLAND



Courtesy "Aeronautics," London

A MOORING TOWER FOR AIRSHIPS, WITH THE R-24 FASTENED HEAD ON attention microscopical and telescopic studies were then receiving.

Francis Bacon (1561-1626), René Descartes (1596-1650) and Gottfried Leibnitz (1646-1716), in England, France, and Germany, respectively, lent powerful aid to the advance of science at this time.

Bacon's great learning enabled him effectively to describe scientific methods and to direct scientific criticism. He attracted general attention to scientific methods based on inductive processes.

Descartes, seeing that the world's best intellects had long been exercised with philosophy and metaphysics, without discovering anything with certainty, resolved to accept no beliefs upon the authority of any name or reputation. He would reach his own conclusions based upon the scrupulous examination of data. He hoped to solve the mysteries of nature by the aid of mathematics and geometry, and developed the Cartesian philosophy.

The mathematical works of Descartes are now better known than his general scientific ideas. He published in 1637 his "Discourses on Method" and on Geometry. In the last-named work, suggestions are given for the development of analytic methods. It has been said of his formulæ that they are even cleverer than himself. The general use of his analytic methods by other mathematicians resulted in the solution of many scientific problems that had been handed down for centuries as insoluble.

Descartes also advanced algebra. The application of the doctrine of curved lines to algebra greatly enlarged the scope of its usefulness. In making these innovations, Descartes introduced the methods and symbols of modern exponental notation. The English mathematician Wallis was also an important agent in the development of mathematical notation. He based his work on the Greek notation and that of Nicolas Chuquet (1484), J. Bürgi, Thomas Harriot (1631), Johann Hudde (1659), and others. Descartes was familiar with the writings of these scholars and, undoubtedly, was influenced by them.

Roberval, Fermat, and Pascal were contemporary mathematicians in France and left great names in the history of the mathematical sciences. They all made contributions which permanently enriched mathematics and made further progress in other sciences possible.

The geographical sciences now began to attract attention. The new scientific instruments made it possible to collect data in all parts of the world that was needed in unraveling scientific mysteries.

William Dampier (1653-1715) was one of the pioneers in scientific voyages of discovery. In voyages to the Orient and Australasia he collected much important data on zoölogy, botany, meteorology, the winds, tides, currents, and on fish and sea life. His book on winds became the first great standard work on meteorology.

The doctrine of spontaneous generation had long held sway in Europe. The Greeks entertained it and it was accepted as true in the time of Martin Luther. Francesco Redi (1626-1697), an Italian biologist, showed that when the flesh of dead animals is protected it remains fresh. The Abbé Spallanzani (1729-1799) carried Redi's theory further and showed that microbes and bacteria do not develop in concoctions which have been boiled and sealed. Here we note the beginning of antiseptic science.

Under the leadership of Bacon in England, Calvin in France, Luther in Germany, and Knox in Scotland, European thought was being stirred up while the great discoveries just related were being made. Just as Boyle's chemical discoveries caused the divorcing of chemistry from alchemy, and the naturalistic philosophy of the times led to the specialization of scientists and the breaking off of philosophy from science, so the intellectual awakening aroused by Bacon and his contemporaries led to the suppression of belief in witchcraft and to revolutionary ideas in religion and ethics.

Locke endeavored to base a "rational Christianity" on the ground of experience. Until his times, theology was tangled up with a maze of physical problems which dismayed even such intellects as those of Newton, Hume, and Locke.

Newton's researches were chiefly based upon mathematical and astronomical problems. While a student at Cambridge in 1660, he studied the works of Descartes, Kepler, Van Schooten, Barrow, and particularly those of the Greek and British mathematicians. The works of J. Wallis were very valuable to him. The "Arithmetic of Affinities" of Wallis drew his attention to astronomical problems and thus led to his great triumphs later on.

Newton's "Principia" has already been referred to as being one of the greatest works of the intellect ever produced.

The result of Newton's meditation upon the nature of the central force that keeps the planets in their courses was that he furnished a mathematical basis for Kepler's laws by proving that if the planets describe elliptical orbits about the sun, the force acting toward the sun, keeping them in revolution, must vary inversely as the square of the distance. On the revolution of the moon around the earth he found a practical confirmation of this law of gravitational attraction. He then took up the study of motion in general and showed that every particle of matter attracts every other particle in accordance with the same principle of inverse squares.

Botanical gardens were established in Padua in 1545, and not long after in Pisa, Leyden, Paris, and London. Much attention was devoted to medicinal plants, and numerous herbal books were published. Malpighi, Grew, and Camerarius (1665-1721) published works on botany and plant morphology. Ray and Linnæus (1707-1778) studied the classification of plants and compiled textbooks of descriptive botany.

Buffon (1707-1788) published his famous "Natural History of Animals" which did for zoölogy what the works of Linnæus did for botany.

Looking backward, we can now see that all scientific knowledge has been gained by the trial and error method and cumulative analyses of a multitude of observations. Progress is not made uniformly but in a recurrent, cyclic manner. Reactions follow advances, but in the end all goes forward.

CHAPTER IX

PRELUDE TO MODERN SCIENCE—THE EIGHTEENTH CENTURY

WHEN the eighteenth century opened science had begun to make men think, and the works of the great scientists had changed the trend of thought on all sides. Liberty of conscience, of worship, and of opportunity were demanded, as well as representative government, economic freedom, and individual equality before the law. Men wanted to be free agents. The philosophical writings of Berkeley, Locke, Hume, Spinoza, Voltaire, Rousseau, and others supplemented the books of the scientists and promoted rational thinking. Syllogistic reasoning displaced the practice of accepting beliefs upon authority. This change in public thought reacted most favorably upon science.

Gottfried Wilhelm Leibnitz (1646-1716) conceived matter as a plurality of simple forces. Many kinds of matter, he said, exist. There is no single natural force, but an infinite number. Each force is represented by some individual substance. Force is indivisible, immaterial, and unextended. Simple forces he called essential forms, units, atoms, or monads. The monads are not mathematical points, nor physical points. Real points are metaphysical. In other words, Leibnitz created a philosophy of eternal force atoms.

The Greeks were taught by Leucippus, Empedocles and Anaxagoras that matter is formed of atoms. Space is infinite; atoms are indivisible. Atoms are in a continuous state of activity. Atoms constitute worlds and planets. Falling through space they give rise to eddying motions by mutual impact. Many philosophers rejected these views. Throughout the ages, however, they were learned by students and when Leibnitz advanced his new atomic theory, the world was ready to consider it. The Leibnitzian monads were like Plato's ideas—eternal purposes. Aristotle held that monads are absolute, indivisible beings. Leibnitz suggested that each monad is in process of evolution and realizes its nature through inner necessity. It is not determined from without. Each form of matter existed in germ in an embryo. Nothing in a monad can be lost, and future stages are predetermined in the earlier stages. Each monad is charged with the past and big with the future. The biologists at this period generally accepted this incasement theory. Caspar F. Wolff suggested, in 1759, that there is an epigenesis or a progressive evolution and differentiation of organs from a homogeneous primitive germ. This view did not meet with approval until Darwin published his great discoveries in the middle of the last century.

The history of the atomic theories furnishes a clear illustration of the long period of preparation that great scientific ideas must pass through before they are united by a generalizing genius of exceptional capacity and launched in the form of a new theory.

Modern mathematical science grew out of the analytical geometry of Descartes. He showed that the true method for the discovery of scientific facts was to accept nothing as true which was clearly not recognizable as true. All assumptions should be proved. Each difficulty should be separately studied. No intermediate steps should be skipped, and details should be methodically enumerated. Thoughts must be guided in an orderly manner, beginning with the simplest characteristics of an object and proceeding in a logical sequence to the most complicated aspects of each subject. Descartes carried out his own rules in his work. His improvements in the differential calculus, and those in the integral calculus made by Cavalieri, and in the calculus of probabilities by Pascal and Fermat, furnished scientists with instruments capable of solving almost every physical problem met with in their investigations.

One of the first results of the new analytical methods was the establishment of the science of optics.

Newton demonstrated that white light is composed of rays of various colors, and that the color reflected by any object is due to the ability of the object to reflect certain rays while absorbing the rest. The Dutch physicist, Huygens, championed the undulatory or wave theory of light. Refraction was explained by both Newton and Huygens, and the latter, while studying the double refraction of crystals of Iceland spar, discovered the phenomena of polarization.

Boyle's chemical discoveries led to much research in chemistry. Black, Bergman and Van Helmont investigated the properties of carbonic acid gas.

Joseph Black treated limestone with acid and collected the gas evolved in a Hales pneumatic trough. He weighed the gas and the remainder of the limestone, finding that what the limestone lost was equivalent to the weight of the gas. He then reversed the process and succeeded in making chalk from a solution of lime. This simple experiment paved the way for chemical analysis and syntheses which have added profoundly to our knowledge of the composition of matter.

Bergman tested Black's gas with litmus and found it gave an acid reaction and in 1779 Lavoisier demonstrated that it consisted of carbon and oxygen.

Priestley and Cavendish, both English chemists, then took up this study. Cavendish treated iron, tin, zinc, and other metals with sulphuric acid and discovered a new gas which he termed hydrogen.

Rutherford discovered nitrogen in 1772 and Priestley isolated nitric oxide, and in 1774 discovered oxygen. In the course of his experiment Priestley also discovered ammonia, sulphur dioxide and other chemicals.

His greatest achievements, however, were the isolation and recognition of oxygen, and the discovery of the composition of water. Following up these discoveries, he noted that the air is not a simple elementary substance, but a mixture of nitrogen and oxygen with several impure gases. The work of this great chemist became as fruitful in the chemical field as that of Newton in physics, astronomy, and mathematics.

Carl Wilhelm Scheele, a Swede, carried out many experiments which resulted in the discovery of tartaric acid, the decomposition of silver chloride by light, magnesium nitrate, magnesia, microcosmic salt, and sulphureted hydrogen, chlorine, hydrofluoric, and other inorganic acids. He also discovered the following organic acids: lactic, gallic, pyrogallic, oxalic, citric, malic, mucic and uric. He isolated glycerin and sugar of milk and determined the nature of hydrocyanic acid, borax, plumbago, Prussian blue, and other chemicals. He invented many new chemical and laboratory processes. Scheele was an apothecary's assistant and lived in poverty. But although his experiments were conducted under disadvantageous circumstances his discoveries ranked him as the greatest chemist of his time and one of the greatest chemical experimenters of all time.

Cavendish established the proportions of the constituents of air, demonstrated the nature of water and its volumetric composition. The character of the experiments conducted by Cavendish, his elegant methods of weighing, measuring and calculating have caused him to be looked upon as the founder of systematic chemistry. He was more scientific in his methods than the brilliant Lavoisier, and much more learned and philosophical than the practical Scheele.

While the chemists were making these great advances there were important developments in physical science. Benjamin Franklin (1706-1790), the first American scientist to acquire world-wide fame, announced that lightning was an electrical phenomenon. In 1752 he showed by his famous kite experiments that atmospheric and machine-generated electric charges are of a like nature.

Franklin suggested to Cavendish certain electrical experiments with a view to studying the electric force between two charges. These experiments led Cavendish to the discovery of the law of electric attraction between charged bodies. Franklin subsequently discovered the law of conservation of an electric charge.

Charles Augustin Coulomb (1736-1806) rendered great service to electrical experimentation. He resurveyed the experiments of Cavendish, Priestley, and other pioneer electricians, and established a theory of molecular magnetization which provided a working formula to explain electrical currents and magnetic fields.

Simeon Denis Poisson (1781-1840) discovered the law of induced magnetism which bears his name.

Luigi Galvani (1737-1798) observed that the limbs of a frog are convulsed whenever they are connected up through the nerves and muscles with a metallic arc formed from more than one metal. He thought the convulsions were due to a peculiar fluid which he called galvanism, or animal electricity.

Another Italian, Alessandro Volta (1745-1827) discovered and explained the theory of the voltaic pile.

Nicholson and Carlisle discovered frictional electricity while William Cruickshank showed that a voltaic current decomposes solutions of metallic salts. William Hyde Wollaston used Cruickshank's discovery to prove that frictional and voltaic electric currents are identical. Humphry Davy (1778-1829) in 1807 established a new voltaic theory which combined the chemical and contact theories previously held, and showed that electrical and chemical attractions are produced by similar causes. Chemical affinity he found to be an essentially electrical phenomenon.

Francis Hawksbee, in 1705, communicated to the Royal Society a monograph which showed that when common air is passed over mercury in a well-exhausted receiver an electric light is produced.

This was the first demonstration of the availability of electricity for the production of light.

Dufay (1699-1739) described positive and negative electric currents.

Watson determined, for the Royal Society, the velocity of an electric current and found it practically instantaneous.

These, and numerous lesser, discoveries did for electricity what the chemical discoveries of Priestley, Cavendish, Scheele, Boyle, Lavoisier, and others had done for chemistry.

The numerous voyages of discovery in the eighteenth century helped to develop the geographical sciences. Special expeditions were fitted out for the acquirement of geographical knowledge without any thought of trading profits. The Jesuits carried out a valuable survey of China and Mongolia early in the century. A Danish scientific expedition studied Arabia, the results of which were published by Niebuhr in 1772. James Bruce visited Abyssinia with the view of solving the ancient problem of the source of the Nile. Mungo Park studied the course of the Niger. Captain James Cook led a scientific expedition to Tahiti with the object of making astronomical observations. This resulted in one of the greatest and most valuable voyages of discovery in history. Cook determined the westernmost point of America in 1778 and his accounts of Bering Sea and Alaska revived interest in the Polar seas, which resulted in numerous Arctic and Antarctic expeditions yielding rich scientific returns.

The Hudson's Bay Company sent out many investigators to determine the characteristics and resources of Arctic America. The Russians did the same for their own northern lands.

These activities of geographical investigators led to improved methods of navigation, nautical surveying, sounding and shipbuilding, besides supplying an enormous amount of scientific data.

The British naval authorities pointed out to King Charles II the need for correct nautical tables. Flamsteed, one of the leading astronomers of the day, was appointed Astronomer Royal in 1675, with the definite object of producing a new catalogue of star positions, tide tables, and other nautical data. He immediately founded the Greenwich observatory, which has supplied the world with data for the navigator.

Bradley, a successor of Flamsteed at Greenwich, made many important astronomical discoveries while carrying on the star maps. He discovered the aberration of light and the mutation of the earth's axis.

Locaille studied the parallax of the sun and made numerous stellar observations at the Cape of Good Hope in 1751. He located the positions of 10,000 stars in the southern hemisphere.

Measurements were made in Peru, Lapland, and elsewhere to discover data regarding the earth's curvature. Pendulum observations to detect variations of gravity were made in many countries. Maskelyne, the astronomer royal, made observations on the transit of Venus at St. Helena in 1761. On this expedition he perfected the method of finding longitude at sea by lunar distances.

Sir William Herschel discovered the planet Uranus in 1781, and subsequently found its satellites. Many star groups, double stars and nebulæ were discovered by him and he found that the solar system is traveling through space in the direction of a point in or near the constellation of Hercules.

Greenwich observatory was publishing at the end of the eighteenth century the Nautical Almanac, and annual reports on star and meteorological observations as well as important astronomical monographs. Similar publications were founded in the next century in France, Germany, and Italy.

The discoveries in mathematics during the eighteenth century included the differential, integral, and other forms of the calculus, differential equations, and various formulæ for dynamics, mechanics, and physical and astronomical calculations. Euler, Lagrange, Laplace, D'Alembert, and Carnot were prominent mathematical investigators.

Heat in earlier times had been regarded as an imponderable substance called caloric which was supposed to be emitted by hot and absorbed by cold bodies. Thus the expansion of mercury was explained by the addition of caloric and not by the increase of distance between the molecules. Francis Bacon and the Scotch chemist Black did the preliminary work which enabled Count Rumford finally to establish the true theory of heat. Watt and Newcomen were attracted by these studies and reduced their theories to practice in the steam engine. Black described specific and latent heat and invented, and used, the calorimeter bearing his name.

Hall invented an achromatic lens for telescopes in 1733, and Dollond, another English optician, improved achromatic lenses and made, in 1758, achromatic telescope objectives. The lenses were primarily designed for astronomical telescopes, but they were also applied to microscopes and other scientific instruments, resulting in improvements in our knowledge of light.

The voyages of discovery, in this century, encouraged study of zoölogy and natural history subjects generally, including mineralogy and geology.

Hooke, Ray, and Woodward made collections of rocks and fossils in England and advanced hypotheses to explain their origins. Lazzaro Moro suggested that fossils must have been deposited in rocks when they were being formed. He also distinguished rock formations by the characteristic fossils found in them. Hutton and Smith then made scientific studies of English rocks, fossils, and earth sculpture, and prepared the materials for the subsequent brilliant discoveries of Lyell.

The first governmental school of mines was established in Freiberg, Saxony, in 1775. This institution, and others which were afterward established in different countries, led to an intensive study of the geological and metallurgical sciences, which eventuated in great advances during the nineteenth century.

Aristotle and Theophrastus in early times, Gesner in the sixteenth century, Ray, Grew, Malpighi and Willughby in the seventeenth century, had been the writers of the principal textbooks on zoölogy. Buffon (1707-1785) and Linnæus (1707-1778) were the founders of modern natural history in the eighteenth century. Buffon described species, while Linnæus classified them. Linnæus named *Homo sapiens* as a distinct species in the order of primates which includes apes, lemurs, and bats, and fixed man's place in nature.

The medical sciences were revolutionized by the researches of Edward Jenner. He applied the scientific methods of the chemists, mathematicians, and astronomers to medicine and through accurate observation, skillful experimentation, careful generalization, and thorough verification, founded preventive medicine. His discovery of vaccination as a preventive for smallpox, communicated to the Royal Society in a very interesting paper in 1798, was the pioneer of the many brilliant advances of our day.

The Freiberg School of Mines, the Woolwich Observatory, the School of Civil Engineering in Paris (1747), the Universities of Göttingen (1737), Bonn (1777), Brussels (1781), Yale (1701) and Princeton (1746) were founded in this century.

Modern industrialism began in the final part of this century. The invention of the steam engine by Watt resulted in giving the greatest impulse to material civilization the world ever experienced. This invention was the direct result of the experimental work of Boyle, Newton, Black, Cavendish, Davy, Priestley, and Lavoisier. It illustrates how the scientific discoveries of one generation furnish the data for the advancement of knowledge by the next generation and how a single invention may change the whole aspect of life, giving employment for vast numbers of people, developing settlement in foreign lands, starting new industries, and extending the fields of commerce. The history of the development of the steam engine from the results of a few basic physical researches by British scientists forms one of the grandest stories in the history of science.

The new aspect assumed by the world as a result of the great scientific discoveries and the increases in industry and commerce which followed them seemed strange to the people who were unused to rapid progress. There was a disturbed feeling akin to fear abroad while the new ideas were being popularized and disseminated throughout the world. The movement in favor of enlightenment was strongest in France because of the social, political, and religious oppression of the people. It ended in the French Revolution, which strengthened the respect for reason and human rights throughout the world.

CHAPTER X

PHYSICAL SCIENCES IN THE NINETEENTH CENTURY

DURING the nineteenth century, the path of scientific discovery might almost be represented by a vertical line. Never before was such rapid and marvelous progress made. The releasing of the mind from the oppressive restrictions of earlier conservative ages liberated the intellectual energies of mankind. A new idealistic philosophy supplanted that of an earlier period and universal attention was given to science and material things. Amidst these changes social science was devolved, and, with it, the study of psychology.

But it was the physical sciences which most felt the stimulus of the new rationalistic spirit.

The relationships between physical magnitudes are established by measurements. When these are accurately ascertained, questions regarding their variable functions can be solved by mathematical principles. Physics is thus linked with mathematics through measurements. The more science advances, the greater is the accuracy needed in physical measurements. The strictness and clearness of experimentation which has been attained in physics has given birth to a science of measurement, which has its own instruments, rules, methods, and formulæ.

Measurement of length is one of the bases of physics. It is a relative operation carried out by comparing the length of one body with that of another. Standards of length are preserved by a Bureau of Weights and Measures in most countries. Delambre, a French authority on the decimal system of measures, taught at the beginning of the nineteenth century that magnitudes as small as the hundredth of a millimeter are incapable of observation. The International Bureau of Weights and Measures now guarantees to determine two or three ten-thousandths of a millimeter. So much has the science of measurement progressed in a century.

The undulations of light rays are used for determining standard lengths. Michelson and Benoit measured a standard length of ten centimeters, in 1894, in terms of the wave lengths of the red, green, and blue radiations of cadmium, and then in terms of the French standard meter. These experiments yielded very accurate results.

The measurement of mass is another important base of physics. Mass is the quantity of matter in a body and the action which gravity exerts on mass is called weight. Weight does not depend entirely upon mass, but also upon the position of the body weighed, because when the body is weighed in one place and reweighed in another, there will be a difference in the force of gravity due to change of latitude and of altitude. National standards of mass have been made of alloys of iridium and platinum.

Many remarkable measurements of time, temperature, and physical constants were carried out during the century.

High and low temperature charts were completed, showing temperatures in the air, the earth, and the sea. Instruments and methods were devised for measuring any temperature whether of high furnace gases or low freezing mixtures.

The measuring units of mass, length, time, and temperature are fundamental, others like velocity, acceleration, power, and area are referred to them. For that reason the latter are called derived units. Many of these are important and call for accurate determinations.

One of the first achievements of the century was the establishment of the doctrine of the conservation of energy.

Francis Bacon had suggested that motion is a phenomenon of heat, and Newton had divined the principle of the conservation of energy, but it was Benjamin Thompson, Count Rumford, who discovered the nature of friction and made the first estimate of the mechanical equivalent of heat. Sir Humphry Davy showed that two pieces of ice could be melted by simply rubbing them together, in a vacuum. But he failed to draw the great inference that this experiment warranted.

If he had observed that the heat could not have been supplied by the ice because ice is an absorber of heat, he would have anticipated the great work done by James P. Joule, an English physicist, who published the results of many experiments carried out by him prior to 1843. His task was to find the exact mechanical equivalent of heat.

His best results were secured by dropping a mass of lead from a measured height and using the energy generated during the descent to operate a revolving paddle in a dish of measured water.

Delicate thermometers recorded the increase of temperature in the water and showed that the descent of 424 grams of lead through a distance of one meter, or one gram of lead through 424 meters, generated sufficient heat to raise one gram of water one degree centigrade (1° C.).

Otherwise expressed, a fall of 772 lbs. of lead through a distance of 1 foot, or 1 lb. of lead through 772 feet, raises the temperature of 1 lb. of water one degree Fahrenheit (1° F.) These 772 foot-pounds, or 424 gram-meters, represent the mechanical equivalent of heat upon which so many important theories have been based. But Joule's equivalent was determined for common air temperatures whereas the specific heat of water increases with the temperature so that the value of the equivalent rises with increased temperatures. Osborne Reynolds, in 1897, found the mean equivalent for temperatures between the freezing and boiling points to be 777 foot-pounds.

The discovery of Joule's equivalent established a relationship between motion or mechanical work performed and the amount of heat generated when work is completely expanded in friction. The same relationships continue good when the work is transformed by indirect means as by generating electric currents or expanding gases. The multitude of elegant experiments used to confirm the truth of Joule's law showed that heat is not a substance, or calorie, but a purely mechanical effect. This great discovery of the relation of friction and heat lies at the basis of electricity, molecular physics, and chemistry, and is the source of the formulæ used by engineers in designing power machinery. The internal combustion engine is largely a result of the discovery of Joule's equivalent and the physical theories derived from it.

This great discovery caused a new theory of matter to be developed. Dalton had suggested, when applying the atomic theory to chemistry, that when two elements combine to form a third substance, it is probable that one atom of one element joins itself to one atom of the other, unless some exceptional condition exists. When water is formed by bringing oxygen and hydrogen together, he supposed that one atom of oxygen combined with one atom of hydrogen. Gay-Lussac subsequently proved that not only does one volume of oxygen combine with two volumes of hydrogen (not one as Dalton believed) in the production of water, but that nitric and carbonic acid gases combine with ammonia gas in the ratio of 1:1 or 1:2. He also demonstrated that one volume of nitrogen united with three of hydrogen form ammonia, and that carbonic oxide burning in a mass of oxygen consumes half its volume of oxygen. He concluded from these and other facts that gases always combine together in simple proportions by volume and that the apparent contraction of volume they show on combining bears a similar simple relationship to the volume of one or more of the gases.

Avogadro, working on Gay-Lussac's experimental data, suggested that the number of integral molecules in any gas is always the same for equal volumes, or is always proportional to the volumes. He also suggested that equal volumes of different gases at the same pressure and temperature contain the same number of molecules. Experiments on alcohol made by Williamson raised doubts as to the validity of Avogadro's hypotheses when applied to chemical combinations. These doubts were cleared in 1860, when the new chemical atomic weights and formulæ were introduced into English textbooks.

The molecular theory of matter derived from these experiments supposes that all visible forms of matter are aggregations of simpler and smaller chemical elements. Mendeléeff and Newlands showed that the physical and chemical properties of the elements are functions of their atomic weights.

Investigations of radioactivity and the observations based upon the passage of electric currents through gases have recently modified our views with respect to the atomic theory, but these points will be dealt with in the chapter dealing with radiation.

Questions regarding the eventual loss of energy in matter are best studied in gases. A considerable number of important investigations are now being carried on in Europe with the view of tracing the interchanges of molecular energies in gas molecules. Maxwell and other investigators found long ago that the motion of molecules cannot go on perpetually. The energy of motion will in time be frittered away by friction, air resistance, collisions with other molecules, vibrations set up by collisions, and other molecular movements. It has been found that the energy which is dissipated by air resistance is transformed into energy in the air. That which is lost by collisions is converted into internal vibrations within each molecule. The question now arises as to what effects are exerted on a gas. It involves the effects of the communicated internal molecular vibrations and their transference of energy to the surrounding medium. What is known as the Quantum dynamic theory has been proposed to account for this phenomena. Quantum dynamics appear to be distinct from the Newtonian.

Carnot and Clausius discovered that the motive power of heat is independent of the agents brought into play for its realization. The motive power of a waterfall depends, for example, on its height and on the quantity of water falling within a given time. Clausius stated the Carnot idea in mechanical terms by saying: That in a series of transformations, in which the final is identical with the initial stage, it is impossible for heat to pass from a colder to a warmer body unless some other accessory phenomenon occurs at the same time. A heat motor, which, after a series of transformations, returns to its initial state, can only supply work, or power, if there exist two sources of heat, and if a certain quantity of heat is given to one of the sources which can never be the hotter of the two. The output of a reversible machine working between two given temperatures is greater than that of any nonreversible engine, and it is the same for all reversible machines working between these two temperatures.

Clausius showed that this principle conduces to the definition of an absolute scale of temperature and there is another factor assisting in restoring physical equilibrium which he termed entropy. It is a variable which, like pressure or volume, serves concurrently with another variable to define the state of a body.

These discoveries of Carnot and Clausius showed the impossibility of finding a source of perpetual motion and helped to solve many of the difficulties in securing efficiency from internal combustion engines. Industrial, as well as scientific results of immense importance have developed from these principles.

Theories on the compressible fluids and elastic equilibrium were developed as the result of work done between 1875 and 1896 by J. W. Gibbs, Helmholtz, Duhem, and others on internal thermodynamic potentials. These theories have proved of incalculable value in elucidating electrical and radiation phenomena.

Another discovery of Gibbs, made in 1876, has also had brilliant results. It is known as the Phase Law. The homogeneous substances into which a material system is divided is called a phase. Carbonate of lime, lime, and carbonic acid gas are the three phases of a system which comprises Iceland spar partially dissociated into lime and carbonic acid gas. The number of phases, combined with the number of independent bodies entering into the reactions, fixes the general form of the law of equilibrium of the system. This discovery of Gibbs has resulted in greatly extending the field of physics. It is of importance in molecular and atomic investigations, in osmosis, electrolysis, and in most questions dealing with thermodynamics.

Light is generally defined as the sense impression received by the eye. It was formerly believed that it was caused by streams of corpuscles emitted by the source of light. This was known as the emission theory. Early in the nineteenth century, the undulatory displaced the emission theory. According to this, light is a transverse vibratory motion extended longitudinally through the ether.

The experiments of Faraday, Maxwell, Fresnel, Hamilton, Green, and others suggested that the undulatory theory required for its validity a new medium different from the atmospheric air and from every substance known to man. Just as the results of investigations into reflection, refraction, diffraction, and polarization showed that the old corpuscular theory of light was untenable, so these experiments seemed to cast doubt upon both the undulatory and emission theories.

Fresnel, when studying problems in polarization, noticed that a theory of light proposed by Hooke appeared to be true. Hooke asserted that light vibrations are not longitudinal but transverse.

Fresnel found by his experiments that the idea of longitudinal vibrations acting along the line of propagation in the direction of the rays would not explain the polarization changes in light. They suggested that there was a transverse movement perpendicular to the ray. When Fresnel's researches were published, physicists realized that if the transverse direction of luminous vibrations was denied the undulatory movement of light would also be denied. Now transverse vibrations cannot exist in any medium resembling a fluid, because it is characteristic of fluids that, so long as the volume continues constant, its different parts can be displaced without the appearance of any reaction. This necessitates the assumption that light needs a solid body for its transmission and Lord Kelvin asserted that this body must be a solid more rigid than steel.

When the vibratory theory was accepted, it became necessary to investigate the nature of the ether and to determine its characteristic properties. Neumann, MacCullagh, Green, and Stokes then developed an elastic solid theory of the ether.

The experiments of Lord Rayleigh, Lorentz, Drude, Larmor, and others suggested that light is identical with electromagnetic disturbances and, consequently, is an electrical phenomenon.

Some of the finest developments in physics during the nineteenth century were in the realm of electricity. They resulted in an enormous extension of the use of electricity in industry and commerce and led to the investigation of radioactivities of various kinds and these in turn are developing investigations of a most brilliant character.

CHAPTER XI

THE NATURAL SCIENCES

MANIFESTATIONS of animal life are everywhere visible. They may be seen on mountain peaks, in desert plains, and by the seashores. Even the bleak arctic ice fields have their faunas. This extraordinary distribution of life has attracted attention since the dawn of history. Primitive man, by his often beautiful cave drawings, indicated that he studied intimately the wild life surrounding him. The basic facts of natural history were studied by the early peoples of the Near East. The Greeks prepared many books on natural history and anticipated modern evolutionary theories. The natural sciences, however, made slow progress until toward the end of the eighteenth century when Linnæus and Buffon began their great works. When the nineteenth century opened, the broader fields of nature were segregated, classified, and described. Linnæus took broad views regarding the principles of classification based upon general structure, and his work was enlarged and improved by Cuvier.

Buffon contributed suggestions regarding the probable mutability of species with respect to changes in environment, and improved on the old Greek evolutionary ideas by formulating a definite theory of the causes of mutability. He was an important agent in promoting the modern theories of evolution in zoölogy and botany, which have done more than anything else to augment our knowledge of terrestrial life.

The numerous scientific exploring expeditions in the eighteenth and nineteenth centuries collected an enormous amount of data regarding animals and animal life. Early in the nineteenth century this data was worked up and classified. It soon became apparent that the range of any given species of animal is strictly limited. A new science, that of the geographical distribution of life, was developed. This has been very fruitful in defining the true home areas of all species of animals, insects, birds, and fish, and locating their principal paths of migration.

The world has been divided into about a dozen terrestrial life regions, subregions and transitional regions. These have been mapped and described. The work of Dr. A. R. Wallace, in 1876, showed the comparative importance and extent of these life zones and their variable richness in zoölogical forms, the relationships of the species in different zones, and their degrees of isolation. The descriptions of these great geographical zones fill many interesting volumes and cover all the important forms of existing life.

The naturalists who studied particular zones, or classes of animals, frequently did extraordinary work. The bird studies in North America, recorded in a series of wonderful paintings by Audubon, and the studies of Fürbringer and other naturalists, are comparable with Wallace's great book on the Geographical Distribution of Animals, published in 1876.

The morphological researches of Parker, Huxley, Quatrefages, Owen, and others revolutionized many of the subdivisions of natural history and led to important discoveries in biology.

The effects of climate upon the development, migration, and decline of species and upon the extension and upbuilding of civilization have been minutely studied. Kropotkin showed that climatic changes in Asia drove the hordes of native tribes into Europe at early periods. They were forced to migrate on account of droughts leading to a food shortage. Many historical events have been shaped by climatic factors. Just as men who inhabit dry districts are usually nomads on account of their need of seeking new food supplies, so animals and insects are forced to migrate for a similar reason. The life changes wrought by disease epidemics under climatic influences have also been studied and have shed much light upon the origin and development of many organs and upon the habits of animals. Some of the chief inferences arising from investigations on the effects of climatic variations on life are that certain types of climate favor the development of certain animal species; certain climates have prevailed in historical times in centers where civilization flourished greatly. Therefore it may be presumed that definite climatic conditions are required for the specific development of each type of species and for each kind of civilization. Just as history shows that one of the many conditions of human progress has changed repeatedly from century to century on account of variations in climatic factors, so these stimuli have, from the earliest times, swayed and modified all classes of organic life. Climate serves to develop, retard, or extinguish animal characteristics, habits, and development. The study of the rôle of climate in modifying living conditions has disclosed data which throws much light on the philosophical problems surrounding organic life, its laws and progress.

The voyage of the *Beagle* in 1831, for a scientific cruise to South America, with Charles Darwin aboard as naturalist; that of the Ross Antarctic expedition in 1839, with Sir W. J. Hooker as botanist; that of the *Rattlesnake* for Australia and the South Seas in 1846, with T. H. Huxley as surgeon, resulted in the assembling of scientific data in natural history fields which, when classified and developed, revolutionized the natural sciences.

The work of the *Challenger*, in 1872, and many other memorable British scientific expeditions augmented and confirmed the data collected in the earlier explorations.

Harvey's explanation of the movement of the blood by the pumping pulsations of the heart quickened interest in biology. Mayer and Helmholtz, when chemists, had succeeded in artificially making urea and sugar and investigated living organisms from the viewpoint of mechanisms operated on the principle of the conservation of energy. They traced the manifold functions of the body to chemical and thermal energies developed by the destruction of food.

These valuable discoveries were augmented by Schleiden and Schwann, showing that all organisms are built up of living cells. The offices performed within cells by colloids and solutions, and in the nerves by electric movements, were traced.

Investigations into the most minute forms of animal life also furnished startling results. Schwann found, in 1838, that fermenting yeast consists of living vegetable cells, and that organic putrefaction is caused by the activities of such cells. Louis Pasteur (1822-1895) demonstrated that the presence of bacteria in any animal is always due to the entrance of bacteria and microbes from the outside, or by means favoring the abnormal increase of existing germs. He also showed by experiments that diseases like chicken cholera, phylloxera, or the silkworm disease are caused by particular microbes. These discoveries led to the tracing of many common diseases to their special living germs.

While these impressive additions to scientific knowledge were being made, other naturalists were studying the instinctive emotional and intelligent behavior and psychology of animals, both singly and in herds. Animals and insects were found to display signs of intelligence, sometimes of a high order; to live socially, in many cases; and to play and court with emotional attributes. Throughout the animal kingdom, until man is reached, animals are guided in their activities by self and racial preservation.

Play was found to be a fruitful factor in animal education, even in minute insects. The behavior of any animal does not stand alone, but is related to that of others. Animals which hunt, or are hunted, combatants, rivals, mates, and enemies, react upon one another.

Entomology, the science of insects, has been extensively systematized. Practically every phenomenon relating to the insect metamorphosis has been disclosed. The works of Binet, Lubbock, Fabre, and many others have illuminated the psychology of insect life. The charming writings of J. H. Fabre on the life of a fly, on the mason bees, the hunting wasps, the life of a caterpillar, of a grasshopper, of the sacred beetles and other insects, are as thrilling and instructive as any masterpiece of romantic writing. What could be more interesting than Fabre's account of his observations on the glowworm, when he discovered that its luminescence is due to oxidation by air forces through a special lightning tube, and that it occurs in males as well as females and in the eggs and grubs likewise? He shows that the glowworm's life, from start to finish, is one carnival of light. The females are living lighthouses which brilliantly illumine the wild thyme and other flowering plants they haunt on dark nights, making miniature fairylands in country districts.

Studies in the growth and form of living bodies have opened up many interesting problems in physical biology. The cell and tissue, shell and bone, leaf and flower are various portions of matter, the particles of which are moved, molded, conformed, or shaped in obedience to the laws of physics. Forms like those of the lovely wing scales of butterflies, of lace flies, or the spiral shells of the foraminifera are natural diagrams of the results of physical forces. Biologists not only study the nature of the motions of living organisms as animal kinetics, but also the conformation of the organism itself, whose permanence or equilibrium is explained by the interaction or balance of forces leading to static conditions.

The dynamics of cell formation and cell division and their karyokinetic figure drawings are the result of numerous complex physical force struggles brought about by chemical and physiological reactions. Studies of these have shown that the spermatozoön, nucleus, chromosomes, or the germ plasms, which develop organic life, can never act alone. They must be started by other forces which make them seats of energy.

The experiments of George Rainey on the elementary formation of the skeletons of small animals, of Carpenter upon the formation of shells, and those of Professor Harting on the same subjects, have shown how lime solutions acting in conjunction with gelatinous substances, or membranes, build up the numerous geometric shapes of the frames of so many kinds of primitive organisms, and the scales of fish or the extraordinarily beautiful markings and sculpture of shells.

The application of the Cartesian coordinates to the outline of organisms, skulls, bones, and organs of animals has opened up a new field of mathematics—biological research which has yielded many results confirming theories based on other data and supplying facts of great interest that may at any time result in the establishment of important generalizations.

The fact of beauty in animate nature is so pronounced, and man's contemplative delight in beautiful things is so natural that investigations have been made into the æsthetic emotions of other animals. A vast array of facts has been collected which leaves no doubt of the universal appreciation of beauty. The lovely colors of shells, butterflies and birds, the extraordinary beauty of the designs of the frames of the Foraminifera, radiolarians and sponges, the graceful logarithmic spirals of horns and flower and leaf buds, and the charming flowing lines in the shape of the race horse and gazelle, these elements of organic beauty which emphasize and enhance the forms of animals, all contribute to the general embellishment of nature. The combinations of beauty of form, color, and movements in parrots, humming birds, the fish inhabiting coral reefs, butterflies, and orchids, are always perfect. We likewise find that in all parts of the globe, and in each life zone, organic beauty conforms to that of the landscape and the heavens. The biological significance of this universality of beauty in the organic world will be dealt with in the following chapter.

The fishes of the seas, rivers, streams, and lakes have been studied, classified, and described as completely as the insects of the air, the field, the soil, and those parasitic upon other organisms.

The surveys of the Atlantic have brought to light many types of fish which inhabit only the deepest parts of the ocean. These fish are modified in most extraordinary ways to fit their surroundings. Owing to the darkness of their living zones, they are provided with luminescent appendages which are practically similar to the firefly's and glowworm's electric generators. The lights are formed, as in the insects, by the oxidation of material exuded by the fish.

There are more than 180 families of fishes recorded. Each family contains an average of twenty genera and each genus about five species. The known species of fish are, therefore, between 19,000 and 20,000. The Danish naturalist Hensen found 278,795,000,000 fecundated fish eggs per square mile in the summer waters of the Skagerrack. The waters of the seas from the Arctic to the Antarctic limits are full of fish eggs as well as those of shellfish and sea organisms generally.

This shows that organic life is as abundant in the sea as anywhere on land.

Just as temperature and salinity are the chief agents of oceanic circulation and current movements, so they are the leading factors in promoting the organic life of the sea.

The vast heterogeneous mixtures of living creatures, comprising vegetable and animal organisms, larvæ, and eggs of fish and animals, which are swept hither and thither by the sea tides are called plankton. This term means the living dust or emulsion of the sea.

It has been shown that vegetable plankton is composed of bacteria and adult microscopic algæ, largely of the Diatomaceæ, Peridinaceæ, Cyanophyceæ, and other primary groups.

The animal plankton comprises a mass of microscopic creatures belonging to the Protozoa, Radiolaria, and Globeriginæ. There are also immense numbers of tiny, invisible crustaceans like the Copepoda, and eggs and spores of all kinds of fish and algæ. These organisms are so dense in certain sea areas that their particular colorations are reflected in the water. The Red Sea, for example, is colored by a reddish algæ; the Baltic and ocean areas near Greenland are colored green by swarms of algæ, and certain tropical seas are often brilliantly colored in the same manner.

Plankton furnishes fish with nutriment. The study of the movements of plankton, at seasonal intervals, has led to the discovery of the causes, extent, and results of the migration of the principal commercial fishes. These researches are so valuable that most large nations support marine biological stations and ships to regularly make observations. The Norwegian naturalist Särs, Sir John Murray, the Prince of Monaco, and others have furnished accounts of the life histories, feeding grounds, metamorphoses and migrations of many fishes, and have shown how the inhabitants of the plankton masses live upon themselves or produce nitrifying or denitrifying bacteria, chemicals, and mineral substances like lime, phosphates, and horny membranous material.

The development of biology and embryology, and the peculiar habits and color schemes of certain fish, insects, birds, and animals led to inquiries about design in nature, the causes of the development of species, and the instincts and habits of animals. Erasmus, Darwin, Buffon, Cuvier, and others began these studies, but it was Charles Darwin (1809-1882), who by the publication of his "Origin of Species" in 1859, first furnished many of the keys to the riddles of organic life. The next chapter will show what has developed from his labors.

CHAPTER XII

ORGANIC EVOLUTION, VARIATION, AND HEREDITY

SCIENCE developed when primitive man began pondering over the problems of the creation. He sought the causes of life, of the development of life forms, and the authorship or origin of the uniformity and apparent design in nature. It is, therefore, probable that what we now study as the science of organic evolution is one of the oldest of the sciences. As the ages have rolled on, the origin of life has been explained in turn by theories of: (1) eternity of present conditions; (2) miraculous creation; (3) catastrophism with (a) increases by immigration (b) increases by successive creations; and, finally, by (4) organic evolution.

The term organic evolution means the forming of new combinations of the elements of organisms. It does not mean the arising of an animal or plant out of nothing—a new creation. That idea was exploded long ago. The science which Darwin started surveys the whole course of natural history in terms of four dimensions—length, breadth, depth, and duration. This was the plan which led Darwin to his great discoveries. While studying the minor changes taking place in common animals and plants, and looking over the broad vistas of nature back to the remotest times, he saw how each year countless weak and ill-adapted plants, insects, and animals were killed off. When he reflected that this process has been going on throughout all time, the idea flashed into his mind that it is through this testing ordeal that adaptability of surviving organisms is derived.

One of the grandest conceptions of the human mind is that the apparently complex, inharmonic system of nature has developed from a simple beginning on a cooled globe from a jellylike cell.

The theory of the permanence of species was generally held by biologists before publication of Darwin's first great book. Darwin said that no naturalist of his time doubted the accuracy of the theory of the eternity of existing conditions and they refused to listen to his views regarding the mutability of species.

Darwin put forth the theory of organic evolution by natural selection and the survival of the fittest. The great beauty of this theory lies in its simplicity and its appeal to agencies which we can see in full operation every day and night. The skillful manner in which Darwin marshaled data to substantiate his theory quickly converted the scientific world, and led to revolutionary changes in the general tendencies of knowledge, and in practically all fields of human activity.

Darwin's terse statement of his conception was: "As many more individuals of each species are born than can possibly survive, and as consequently there is a frequently recurring struggle for existence, it follows that any being, if it vary in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance any selected variety will tend to propagate its new and modified form." ("Origin of Species," Intro.)

This statement of the doctrine of the survival of the fittest, suggesting a glimpse at the great pageant of nature from the remotest times, shows how the organisms existing at this moment are the descendants of the victors in the world's greatest battles. The struggles for life, always keen and persistent, shared in by every individual organism, both animal and vegetable, are the instigators of all progress in the natural world. They are nature's means for the attainment of beauty, usefulness, and perfection.

The Darwinian theory was based upon the observed facts that members of any given species are not alike, while their offspring may differ in numerous ways from their parents. The data furnished by zoölogy, botany, physiology, and other sciences supply overwhelming evidence that the present species of animals and plants have arisen through the modification from various causes of many preexisting species. The organisms with which we are familiar owe their characteristics to the accumulation of a long series of changes similar to those that we may see that they are still undergoing.

The methods pursued in studying variation in species, and its important accompaniment, heredity, consists in comparison, statistical examinations, cultural experiments, and crossbreeding.

Evolution is the process of differentiation accompanying the operations of nature. All the great naturalists before Darwin's time noted facts indicating this universal differentiation, but it required the particularly wide sweep of Darwin's mind to phrase and demonstrate it.

The law of origin by evolution, as Herbert Spencer showed, is not confined to the method of bringing into existence new species of animals and plants. The stars, planets, the geological strata and earth contours and forms, human institutions, social customs, and practically everything in nature are obedient to it.

Much research work in evolution has been done since Darwin stated his theory, but the basic principle of the survival of the fittest remains untouched by criticism. Some of his views respecting minor details of selection and the effects of various factors have been modified or enlarged, and many new evolutionary forces have been discovered. It has also been found that a single cause is usually followed by more than one effect.

Weissmann has drawn attention to the importance of adaptations. Most organic beings are usually closely fitted for the conditions under which their lives are spent.

The principal parts of every animal and plant, and all the points in which one species differs from a nearly related species, have been shown to have arisen on account of their usefulness to the creatures possessing them. As natural selection is always progressive, it follows that no adaptation is ever perfect. There is always progress from the useful to the more useful—a continual striving for greater beauty of form and color and higher efficiency.

Works on evolution furnish an abundance of interesting evidence showing how adaptation works. A single instance may be cited here.

One of the Mexican yucca plants common in our Southern States is pollinated by a moth of the Pronuba family. This moth is adapted for its work by several special organs including a special ovipositor and peculiar maxillary tentacles which are not found in other moths. The female moth collects pollen with these tentacles from several yucca flowers, rolls it into a ball and kneads it into a pellet. When the pellet is ready the moth seeks an unvisited flower and, after depositing a few of her own eggs in the ovary, she climbs the style and forces the pollen pellet into the stigma. This is the way the yucca is pollinated and fertilized. Two important purposes are served by this arrangement: a species of plant and a species of moth, together with those dependent upon them, are enabled to survive by this moth's activities. There are many known cases of similar cooperative adaptation to living conditions.

Quetelet, in 1845, followed by Francis Goltin and Karl Pearson, have applied statistical methods in dealing with evolutionary problems, and a new science called biometry has been developed. This science has yielded much important data regarding the effects of inherited characteristics.

The studies of variations in plants by mutations, made by the Dutch botanist De Vries, have opened up wide fields of study regarding the causes of variation. He has shown that increased bulk or better coloration may result from improved nutrition and more light, and that such improved characteristics may be inherited.

A law of ancestral heredity has been worked out for men by biometricians, and this has been confirmed by the experiments of Professor Johannsen, of Copenhagen, on self-fertilizing beans, and by Jennings on protozoa. This hypothesis suggests that every ancestor of a particular man or woman contributes its quota to the heritable qualities displayed by that individual. The average amount of resemblance between an individual and any of his particular ancestors is capable of being numerically expressed.

The experiments and conclusions of Gregor Mendel (1822-1882) tend to oppose the law of ancestral heredity, but it is believed that any exceptional cases may be explained by the operation of special conditions.

Karl Pearson has shown by the analyses of numerous statistical records of Englishmen that by artificial selection any selected characteristic, such as facial contour or stature, can be changed within a few generations. But when the character has been changed about 90 per cent within a short time another method must be employed, because the original one then becomes less efficient.

Individuals in any given population who differ in size from the mean of the population give rise to offspring which differs from that mean value in the same direction but to a smaller extent. The same law applies to the color of the hair or to intelligence or constitution. Selection will always produce a change in the average character of a population taken as a whole. But selection within a pure line, or one which shows only normal variability about a mean or type value, does not produce marked changes.

The usual selection within any particular population consists in the partial separation of extreme types.

The personal characteristics of any ancestor do not influence his descendants. Only the typical characteristics are handed down.

These and many other facts developed by investigations in biometry should be of value in regulating immigration, so as to guard against degenerative influences, and they have greatly increased the efficiency of farming by showing how to improve farm stocks and crops so as to yield larger returns. Farmers have been more ready than politicians to avail of their advantages. We note how the speed of racing and trotting horses, and the milking capacity of cows, have been improved by the past century, but we are doing little to reform national health and efficiency.

Mutation is the name given to the process of origination of a new species or character accomplished by a single step or by a series of steps.

Bateson, in 1894, showed that symmetry is a characteristic common to all organisms. This may affect the whole or parts of an organ. Major symmetry involves the whole organism and minor symmetry only an organ or part. There are meristic variations, involving the symmetrical pattern, and substantive variations involving changes in the constitution or substance of the organism. Red-flowering plants, for example, may yield offspring bearing white flowers. Substantive variations are often discontinuous, or accidental, and are infrequent.

Organic bodies are built up of a number of cells. The living material of cells is protoplasm formed out of many elements, of which carbon, oxygen, hydrogen, nitrogen, and sulphur are the more important. New cells arise from bipartition of existing cells. Therefore by following back the history of any animal or plant we will arrive at a stage when its ancestors had only one cell. Every animal or plant which is propagated sexually actually starts as a cell and develops through its main evolutionary changes in the embryonic state. Cells are liable to all the evolutionary changes that the organism as a whole is subject to.

Studies of embryology have shown that the fusion of biparental reproductive cells results in the formation of a complete new individual which, at the time of the fusing of the two conjugating cells, called gametes, or germ cells, inherits the characteristics of each parent and its ancestors.

The determination of the sex of the cell, plant, or animal, depends upon the presence of extra male or female sex-chromosomes, or sex-determinant fibers of the cell nucleus. Certain animals and plants transmit male characteristics to the female descendants, while the female transmits her characteristics to the male descendants. There are many variations of this kind. These strange movements in heredity are explained by the laws governing chromosomes and idio-chromosomes and elementary cells.

According to the germ plasm theory of inheritance, the separate parts of living organisms are assumed to be represented by separate material particles in the germ cells. In the Mendelian theory each cell is assumed to contain a large number of *ids*, or complete sets of sex determinants, half the total being derived from each parent. This permits the germ cells to contain a certain number of ids from each parent.

Studies of these subjects show that the great harmonies of the natural world are manifested in form, number, pattern, and color, which we find to be basically simple and, when studied systematically, they appear quite clearly, so as to be capable of being described and expressed as laws.

The study of the agencies under social control which may improve, or impair, the racial qualities of future generations, either physically, socially, or mentally, is called the science of eugenics. This new science is another outgrowth of the revolution in intellectual development originating with the publication of Darwin's theory. Sir Francis Galton was the pioneer worker, and he has been followed by Pearson, Yule, Lombroso (1836-1909), and others.

Eugenic studies, confirmed by those of genetics and biometry, show that the human race, which is the masterpiece of Nature's evolutionary processes, is capable of much further development through the careful guiding of the very forces used in evolving man to his present state. Man can be improved by selection and education to greater beauty, clearer intellect, larger stature, sounder character, and better physique. The measure of what man has done is a good criterion of what he is capable of doing under the guidance and encouragement of science.

Genetics, the study of the hereditary phenomena of organisms, is based upon the law of inheritance discovered by Mendel in 1865. This law relates to the inheritance of certain definite characters called allelomorphs. These characters are found to group themselves in pairs which exhibit more or less antagonistic qualities. A knowledge of these characteristics is necessary to conduct selective breeding experiments scientifically. It is found that when two similar germ cells, each bearing the same new combination of allelomorphs, meet in fertilization, they result in the development of a new zygotic combination of a pure type which breeds true. This accounts for the establishment of new species. When, on the other hand, the coupling is unequal, or only partial, there will be irregularities in the characters of the offspring and no new species is likely to develop. Immense value is attached to this law by naturalists working in all fields. The three new sciences of eugenics, genetics, and biometry have prepared the way for a regeneration of humanity through breeding in the desirable and breeding out the undesirable.

CHAPTER XIII

CHEMICAL AND BOTANICAL THEORIES

THE World War served to demonstrate the degree of perfection which has been attained in chemistry. The wonderful high explosives used, the poisonous gases, the lubricating and motor oils and a multitude of valuable chemicals employed for military and naval purposes, many of which were developed at short notice, showed the modern chemist's command of his science. Yet chemistry is a new science. Practically it began with Robert Boyle, in England, in 1661. Boyle conducted experiments on the rarefaction of air and the nature of gases, and in his book, "The Sceptical Chemist," he made this remarkable statement: "I am apt to think that men will never be able to explain the phenomena of nature, while they endeavor to deduce them only from the presence and proportions of such or such ingredients, and consider such ingredients or elements as bodies in a state of rest; whereas, indeed, the greatest part of the affections of matter, and consequently of the phenomena of nature, seem to depend upon the motion and contrivance of the small parts of bodies."

Thus Boyle anticipated the chemical theories of matter developed in the nineteenth century.

Lavoisier, about 1777, advancing from the quantitative study of one chemical change to another was able to describe many processes, and to distinguish between an element and a compound. He cast aside all the alchemical formulæ and expressed the results of his experiments in fractions and proportions.

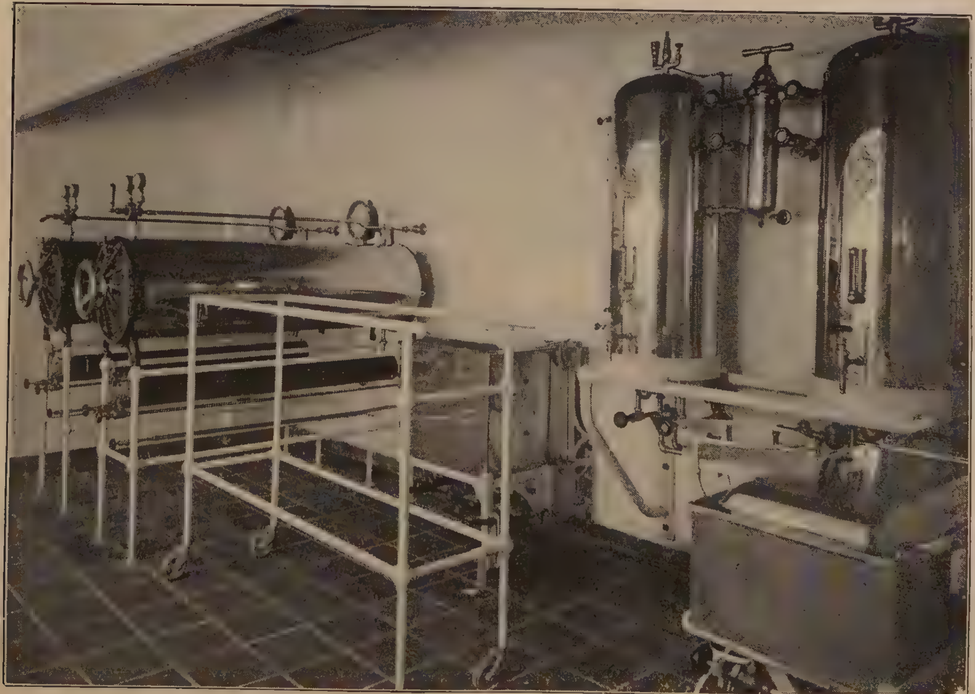
J. B. Richter between 1791 and 1802 made a series of experiments by which he secured the weights of various bases neutralized by constant weights of several acids, and the weights of several acids neutralized by constant weights of several bases. He found that the composition of chemical compounds is constant, as had been assumed by Lavoisier and Boyle.

Dalton described the atomic constitution of gases in 1808, and sketched the law of multiple proportions in chemical combinations and described binary, ternary and quaternary combinations.

Prussic acid was investigated by Gay-Lussac in 1815, when he isolated cyanogen and found that although it is a compound it plays the part of an element with hydrogen and the metals. Berzelius also found that ammonium possessed all the properties of an alkali metal.

Ten years after the above discoveries were made, Faraday prepared a compound of carbon and hydrogen from liquefied coal gas which led to the general study of isomerism and the great discoveries of the organic radicals with their important combinations.

When isomeric combinations were studied by Jacob Berzelius (1779-1848), he was led to devise a means of expressing organic reactions. He wrote to Wöhler and Liebig a letter outlining his new method in which he said: "From the moment when one has learned to recognize with certainty the existence of ternary atoms of the first order which enter compounds after the manner of simple sub-



Photo, Fifth Avenue Hospital

ROOM IN WHICH INFECTED ARTICLES ARE STERILIZED

MODERN OPERATING ROOM IN A PARIS HOSPITAL. IT IS FITTED WITH A GLASS DOME AND RADIO MICROPHONES FOR THE USE OF STUDENTS AND DOCTORS WHO WISH TO WATCH THE OPERATIONS AND HEAR DISTINCTLY THE COMMENTS OF THE SURGEONS stances, it will be a great relief in the expression of the language of formulæ to denote each radical by its own symbol, whereby the idea of composition it is desired to express will be placed clearly before the eye of the reader."

An example of this method of expressing reactions was given in the case of the action of chlorine on benzoic acid. He wrote B_2O for benzoic acid, B_2Cl_2 for chlorbenzol and B_2+NH_2 for benzamide. With certain simple improvements made subsequently by Gmelin, the method devised by Berzelius was generally adopted and is in use to-day.

The numerous investigations now being made with the object of discovering the various combinations of the elements led to many improvements in chemical analyses. When we read Berzelius' accounts of his analyses they seem to have been written only yesterday. He and his contemporaries developed analytical and synthetic methods to almost the efficiency that we see to-day.

We also owe to Berzelius a table of the elements showing their electrical qualities, an electrochemical theory, identifying chemical affinity with electric attraction, and a new nomenclature, besides a vast amount of descriptive chemistry.

The discovery of the specific heats of various solid elements by Dulong and Petit in 1819, and Mitscherlich's finding of the isomorphic phenomena in 1818, resulted in the publication of a new atomic weight table in 1826 by Berzelius.

The experiments made in isomorphism by Mitscherlich led him to discover dimorphism and study crystallography. He used his knowledge of crystal measurement extensively and developed synthetic chemistry and the laws of crystallization.

Thompson, Prout, and Wollaston were working on problems in England similar to those examined in Sweden by Berzelius and Mitscherlich.

Molecules were discriminated from atoms in 1826 by Jean Baptiste Dumas and Faraday discovered his law of electrochemical action in 1834.

Organic chemistry originated in Manchester, England, when Dalton read his paper before the Manchester Philosophic Society in 1803 on the theory of atomic weights. This paper led Gay-Lussac, Thenard, Berthollet, de Saussure and others to study organic analyses as devised by Dalton. Gay-Lussac and Thenard greatly improved Dalton's methods and in 1824, as shown by Chevreul's work on fats and greases, organic analyses had been brought to high perfection.

The phenomena of substitution in hydrocarbon compounds like the petroleum oils were studied by Laurent who proposed a theory of basic nuclei. $C_{10}H_8$ being the nucleus of the naphthalene group and C_2H_4 that of the ethylene group, derived nuclei can be obtained from these by substitution and hydrogen and other elements acting on derived nuclei from numerous hydrocarbon series.

The homology of the hydrocarbons was discovered by Gerhardt in 1844 while he was investigating the alcohols. Wurtz's work on the ammonia compounds, Williamson's on the ethers, Hoffmann's on anilines, Graham's and Liebig's on the citrates, and Frankland's, Kolbe's and Kekulé's work on other compounds raised organic chemistry to such a high plane that industrial chemists were able to use their theoretical conclusions and build a great number of important industries upon organic principles.

Lothar Meyer, in 1868, and Mendeléeff, in 1869, published atomic weights showing improvements in the theories of valency and the interrelationship of atomic weights. Mendeléeff was able to predict from the vacant positions in his table the discovery of important new elements. A number of these elements have since been discovered.

The aniline dye industries have grown out of the discoveries of many chemists. The basic work was done by Faraday, Laurent, and Runge, who isolated valuable hydrocarbons from coal gas tar. Hoffmann discovered aniline and Perkin obtained mauve in 1856 by the oxidation of aniline with chromic acid. It was this and subsequent discoveries by Perkin which gave the greatest impetus to synthetic dyes. The solubility of a dye was improved by increasing its acidity (sulphonation) or by increasing its alkalinity (alkylation). Similar dyes are now made by the same methods from many common aromatic substances.

The chemistry of explosives was developed by Van Helmont, Debus, Bunsen, Abel, Nobel, and others. Fulminates were used for detonators by Ure in 1831, picrates were employed as explosives by Fontaine and Abel; nitrocellulose (guncotton) discovered by Braconnot in 1832 and used as an explosive by Schönbein in 1846, and nitroglycerine was produced by Sobrero in 1847. Smokeless powders made from guncotton, dynamite, and gelatine were introduced by Nobel in 1890.

Pasteur showed, in 1848, that when the double sodium ammonium racemate was crystallized, two kinds of crystals separated from the solution. When one set of crystals was dissolved in water the solution rotated a beam of polarized light to the left, while the aqueous solution of the other crystals rotated the light to the right. These crystals thus revealed their geometrical properties with perfect light while in solution in water. Pasteur noted that optical activity of this kind is the expression of some form of molecular asymmetry.

Le Bel in 1874 also pointed out that optical activity is an expression of the asymmetry of the chemical molecule and showed that all carbon compounds which are optically active contain a carbon atom combined with four different atoms, or groups. Van't Hoff showed in 1875 that there were definite relations between the arrangements of tetrohedral carbon atoms and polarization phenomena and established the theory of such atoms.

Willard Gibbs, of Yale, discovered what is known as the phase rule, which shows, by thermodynamic methods, how the conditions of chemical equilibria can be systematically grouped.

Van't Hoff, Pfeffer, and others noticed that when two solutions are brought together, if one is more concentrated than the other, diffusion begins in the concentrated and extends to the weaker solution. This shows a talent force in concentrated solutions which is now known as osmotic pressure. Van't Hoff and Arrhenius showed that for comparable concentrations the osmotic pressure of a solution is exactly equal to the pressure of a gas. These discoveries led to a brilliant series of investigations into electrolytic chemistry.

The theory of electrolytic dissociation advanced by Ostwald shows that the molecules of electrolytes in aqueous solutions are broken down into electrically charged parts called ions. In very dilute solutions the dissociation of strong acids, bases, and salts is practically complete as was suggested by Williamson in 1851.

Catalysis, or reaction brought about by agents which do not enter into the chemical changes, was discovered by Berzelius. Ostwald investigated and developed catalytic reactions which are now extensively employed in industry, particularly in refining oils and in the fixation of nitrogen. Hot platinum, for example, is used to act catalytically in causing sulphur dioxide and oxygen to combine and form the basis of sulphuric acid, sulphur trioxide.

One of the most important applications of catalysis to industry is the Haber process for securing nitrogen from the air. When air and hydrogen are compressed and heated to a high temperature in the presence of a catalyzer such as metallic uranium or iron carbide, the nitrogen and hydrogen combine and form ammonia.

The experiments of Sir William Crookes on vacuum tubes subjected to electrical impulses led the way to the discovery of radioactivity, and investigations of radium have revolutionized our conceptions of the nature and properties of matter.

The discovery of helium, argon, the niton emanation from radium and other elements by Ramsay, Collie, Soddy, and others will be referred to later.

Carl Linnæus, who is called the father of modern botany, established the genera and species of plants upon philosophical principles. He established a binomial nomenclature and formulated modern descriptive methods. Thus he prepared the way for the systematic works of De Jussieu and De Candolle.

De Candolle, in 1819, published a new method of classification based upon morphological characters.

He defined and illustrated the doctrine of the symmetry of plant organs and asserted that a natural classification must be based on a plan of symmetry.

The relationships between the endosperm and embryo were shown in 1810 by Robert Brown in his monograph on the Australian Proteaceæ. The morphological nature of seed reserves was described by him. He also discovered the functions of the cell nucleus and founded cytology. He showed that the oscillation of minute particles in the fluids of plants when viewed under high microscopic powers, known as the Brownian movement, is due to purely physical causes.

Schultze, Unger, and others, working on suggestions previously made by Knight, Robert Brown, and Hooke, discovered the rôle of protoplasm in plant cells. Alexander Braun and De Bary correlated the movements of protoplasm with the locomotory movements of free zoögonidia and the amœboid movements of Mycetozoa. These investigations directed research to further studies of the structure and constitution of protoplasm and helped develop the cellular theory.

The Algæ were studied and classified by Naegeli, Unger, Von Mohl, Haustein, and others in 1847-1850.

The vascular cryptogams were studied by Hofmeister. He found that the alternation of a sexual with an asexual generation is common to all plants of the mosses, vascular cryptogams, and gymnosperms, as well as among angiosperms.

Hofmeister's work led to appreciation of the fact that a natural system of plant classification must be based, not on balancing the values of the morphological parts of fruits and flowers, but on the anatomy of the real and concealed reproductive organs.

Fossil botany, or paleophytology, was founded, in 1828, by Adolphe Brongniart. Witham, Goeppert, Unger, Corda, and others helped to advance this science.

The publication of Darwin's "Origin of Species" in 1859 found the various botanical sciences already well worked out by numerous capable experts. A huge amount of data and descriptive matter had been assembled and botany, like the other sciences, was ready to be quickened by the Darwinian theories.

The idea of a progressive evolution in plants had been suspected by many botanists, but the genius of Darwin developed it. Living plants were pictured as a multitude of units competing for food, light, air, and room for growth, and struggling against unfavorable environments. The classification of tissues was begun, and the phenomena of absorption of water and salts, the ascent of sap, the absorption of minerals and nitrogen, and metabolism and growth were elucidated. Investigations were made into the nature and functions of chlorophyll and other plant substances. These studies resulted in suggesting means for improving crops by artificial selection, as shown in the work of Luther Burbank.

CHAPTER XIV

GEOLOGY, METALLURGY, AND METEOROLOGY

GEOLOGY is essentially a nineteenth century product. Fossils, minerals, rocks, and rock strata had attracted more or less attention from the earliest times. The Egyptians, Greeks, and Romans had books dealing with such subjects, and Greek philosophers, like Aristotle, lectured upon them. But it was only in the last century that geology was placed upon a scientific basis and began to make progress. The reformation was begun by Cuvier's work on paleontology, the chemical and physical discoveries of the eighteenth century, and the works of Hooke, Boyle, Buffon, Linnæus, and others. The special technique required in geographical research could not be developed until the biological, anatomical, botanical, and physical sciences had been established on a scientific plane. That is why geology remained for so many centuries undeveloped, and then rapidly advanced during the nineteenth century. Its preparation was long and involved, while its fruition was rapid and brilliant.

William Smith (1769-1839), called the father of English geology, was a mining surveyor engaged in making colliery and farm surveys in Oxfordshire and the west of England. His professional work led him to study the coal outcrops, and in 1793 he mapped the inclined coal deposits in Somersetshire. The numerous rock strata accompanying the coal beds contained fossils which he found could be used to identify the beds in that field with others in northern counties. He published an account of this manner of using type fossils for identifying fossiliferous rock formations in 1799, and in 1815 issued his geological map of England, Wales, and southern Scotland. This map showed the advantages that scientific geology and mineralogy offered to industry and caused scientists all over Europe to study geological phenomena and make sketch maps of local geology.

A work on paleontology, dealing with the fossils of the Old Red Sandstone deposits, published in England by Hugh Miller (1802-1856), which had an enormous popularity and has been described as the most fascinating book ever written on a geological subject, followed Smith's "Strata Identified by Organized Fossils." A large amount of mapping resulted from the issuing of these two works. These maps called for detailed descriptions, and these in turn resulted in the accumulation of many interesting data which, when collected, and systematized, led to many important discoveries.

While these authors were preparing their books, Werner, De Luc, De Saussure, Lamarck, and others were working out paleontological problems, Romé de l'Isle, Brongniart, Haüy, d'Aubuisson, and others were building up the science of mineralogy.

"The Theory of the Earth," of Dr. James Hutton (1726-1797), was published in 1785, and in an enlarged form in 1795. This book described the metamorphoses of sand into sandstones, quartzites, schists, and other rock formations; the work of floods and lava floods; the sculpturing powers of streams, rains, and winds, etc. He indicated the effects of the alternate sinking and raising of strata through earth shrinkings and volcanic phenomena, and taught that purely physical causes can be found for every geological effect.

Playfair's "Illustrations of the Huttonian Theory of the Earth" augmented the teachings of Hutton's book, while works by Jameson, Kirwan, Boué, Sir James Hall, Daubrée, St. Claire-Deville, Buckland, Sedgwick, Bakewell, Breislak, Maclure, and others rapidly appeared sustaining the Huttonian, or the Wernerean theories of geological deposition.

The work of James Sowerby (1757-1822), entitled "The Mineral Conchology of Great Britain" and that of James de Carle Sowerby (1781-1871), published between 1812 and 1845, marked the establishment of paleontology as a science. Both father and son were well-trained naturalists and artists, and, like William Smith, reproduced the fossils and their containing rocks to scale and in natural colors. These works greatly simplified the labors of field geologists in identifying rock strata and type fossils.

In Germany geology was worked out by Baron von Schlotheim (1764-1832), Goldfuss (1782-1848), and Count Munster (1776-1844). Brocchi (1772-1826) described Italian fossil strata.

The "Geological Classification of Rocks," of MacCulloch, marked the separation of petrology as a science from descriptive geology. MacCulloch noted that the ancient granites and granite schists are among the oldest rock forms.

Von Humboldt, Murchison, Lyell, De la Beche, Von Buch, Elie de Beaumont, Holley, Geikie, Bonney, Wollaston, Scrope and Daubeny were among the pioneer geologists in Europe, while James Dwight Dana (1813-1895), E. S. Dana, Conrad, Hitchcock, Warren, Lesley, Fremont, and others published descriptive geological accounts in the United States.

References to the geology and minerals of New Mexico were made in Humboldt's "New Spain." Greenhow's work on Oregon and California, published in 1845, and Lewis and Clark's reports added much to our knowledge of American topography and geology. These reports were followed by those of Stanton, Clarence King, Hague, Emmons, Custer, Powell, Davis, Gilbert, Agassiz, and others which dealt with various phases of American geology, paleontology, glaciation, and mineralogy, and prepared the way for the publication of the valuable works of Dana, Williams, Iddings, Washington, Pirsson, Clarke, Grabau, Brush, and others.

The treatment of geological problems from the viewpoint of present causes was begun after the publication of Lyell's "Principles of Geology" (1830-1833). Earlier geologists were aware of the fact that many of the rock formations had been derived from other consolidation of sand and mud beds and by other actions which may be studied in operation to-day. But the systematic manner in which Lyell treated the whole field of geology made such an impression upon geologists that the publication of his great work marked a new era in the science. De la Beche, Buckland, Geikie, Bonney, and other geologists in England; Dana, and a number of scientists in the United States Geological Survey, in America; Vogt and Naumann, in Germany; Studer in Switzerland; Stopanni, in Italy, and many specialists in other countries took up the work of Lyell, and at present practically every important geological factor is known and the effects of its operations have been described.

The succession of life in geological periods is studied under paleontology. This science developed at the same time as systematic and descriptive geology. Many great naturalists have contributed to it. Agassiz, Hall, Dawson, Walcott, Marsh, and others in the United States and Canada; Owen, Prestwich, and others in England; and numerous writers in Europe have published valuable monographs on various phases of fossil and stratagraphical geology.

Paleontology, by fixing the succession of animal and vegetable eras, has served as a basis for measuring time, revealing the antiquity of man and of the principal mammals, as well as showing changes in climate, and in land and sea areas.

The application of geology to many industries called forth another branch of the science known as economic geology. This deals with the origin and geographical distribution of the useful minerals, the derivation of underground waters and petroleum, and the changes undergone by soils.

The first important impetus to economic geology was given by the publication of Whitney's "Metallic Wealth of the United States" in 1854, Von Cotta's work on ore deposits in 1859, and the economic references in the textbooks of the leading European and American geologists. The recent work of Bonney, Groddeck, De Launay, Phillips, Prosepny, Van Hise, Emmons, Le Conte, Lindgren, and others has greatly advanced the interest and usefulness of the science.

These writers carried out an extended series of investigations on the depth temperature and physical and chemical condition of the earth's crust. Chemical analyses of rocks and soils were made and the changes wrought by physical and chemical forces were noted. On these were based theories as to the formation of rocks, soils, minerals, and ore deposits. The erosive properties of soil water were found to be limited to a depth not exceeding 20,000 feet, although hydrostatic water bodies are rarely found as low as half that distance, the rise in temperature precluding their existence. The work of these men revealed the part played by vulcanism in rock changes, and the effects produced through hot solutions and magmatic intrusions.

Various systems of classification of minerals and ore deposits were developed. Richard Beck's, "The Nature of Ore Deposits" (1900), and Lindgren's "Mineral Deposits" (1919), are works which have contributed to the systematizing of economic geology from the mineral standpoint, and the establishment of epochs of metal generation.

The ore deposits of the United States have been described in the monographs of the United States Geological Survey, and by Kemp, Spurr, Grabau and other writers.

This branch of geology emphasizes the strong tendency to concentration shown by mineral elements. All climatic forces are found to aid this work. Underground waters, both flowing and stationary, are powerful assistants.

Other phases of economic geology have been developed in studies of subterranean waters, microscopical petrology and mineralogy, the chemical analyses of rocks, etc. Among the leaders in this work have been Pirsson, Emmons, Iddings, Washington, Van Hise, Clarke, and others.

The enormous metallurgical industries of to-day are all dependent upon scientific principles chiefly discovered and applied in the nineteenth century.

Metallurgists in the previous century knew that by adding certain metals to molten steel it could be hardened. A method of this kind was published by Réaumur in 1722. Tool points, he showed, could be hardened if the steel when red hot was forced into solid tin, lead, copper, silver or gold, thus producing an alloy stronger and harder than the pure steel.

A series of calorimetric researches on metallic alloys, carried on by Bergman, led to the discovery that steel differs from iron merely in the carbon contents. Clouet, in 1798, followed this by an experiment in which he melted up a little crucible iron with a diamond and obtained a mass of steel. This created a sensation and led to many other experiments on the metallurgy of cast and wrought iron and steel.

Thomas Young, in 1802-7, studied the mechanical properties of iron and steel and developed the theory of the modulus of elasticity. A patent was issued to the Rev. Robert Stirling, in 1817, for a regenerative iron smelting furnace. The next year Samuel Baldwin Rogers substituted iron bottoms for sand bottoms in puddling furnaces. Faraday and Stodart produced the first alloy of nickel and steel in 1820, and in 1822 Faraday showed that there is a fundamental chemical difference between hard and soft steel.

The first patent for a hot blast for iron furnaces was granted to James Beaumont Neilson in 1828.

All these discoveries led to important improvements in iron making.

The steam hammer was patented by Nasmyth in 1842, and between 1843 and 1848 Thomas Andrews conducted valuable investigations into the heat of combination.

The ground was now prepared for one of the greatest of metallurgical inventions—the conversion of pig iron into steel by an air blast in a Bessemer converter. This invention not only vastly extended the use of steel, but drew attention to the valuable oxidizing effects of a hot air blast and in that way induced many important improvements in the metallurgy of copper, lead, and zinc.

Siemens, Whitworth, Bell, Graham, Percy, Richards, Martin, Thomas, Holley, Hewitt, Fritz, Howe, Jones, and others made further important improvements in the metallurgy of iron and steel in the United States and Europe.

One of the early American iron smelters was built by Governor Keith, in 1726, in New Castle County, Delaware. A rolling mill and forge were subsequently built at Wilmington. The first American smelted iron was shipped to England from smelters in Maryland and Virginia in 1718. The Bessemer steel process was introduced into the United States by Abram Hewitt at the Troy smelter, New York, in 1865. From these beginnings the iron industries of the United States have grown so that they now produce more than two-fifths of the world's annual supplies.

The alloys of iron and steel have now attained importance and a new science known as metallography has developed. Professor Arnold, of Sheffield, Sherard Cowper-Coles, Roberts-Austen, Sorby, Tschermak, Tschernoff, Wüst, and Ziegler have been active promoters of this branch of metallurgy, and a closely related one dealing with the effects of the heat treatment of metals.

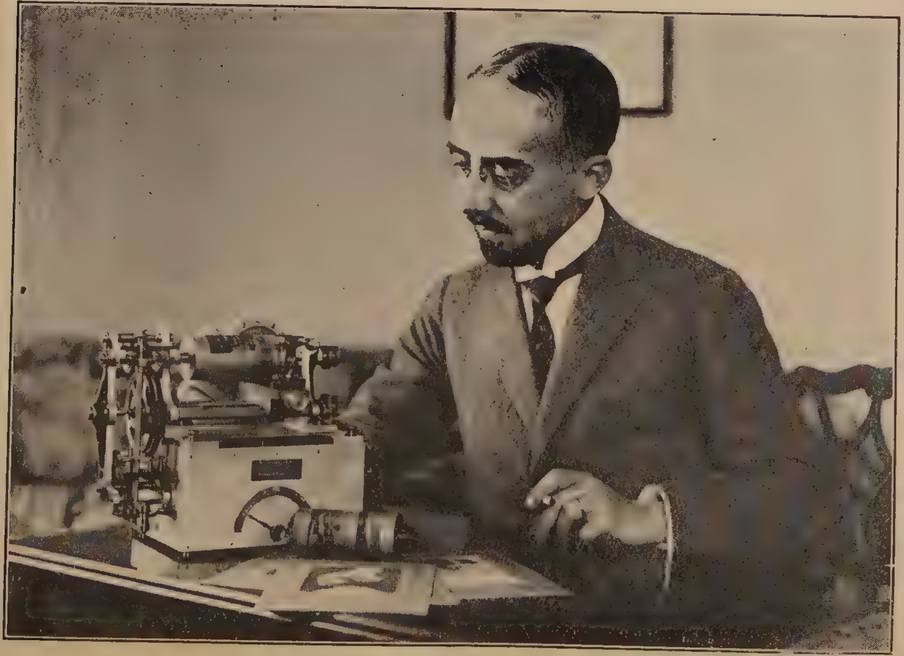
Developments in the iron industries led to others in the metallurgy of copper, lead, and zinc.

The application of the blast furnace to copper, lead, and zinc smelting was chiefly made in America. One of the early furnaces was built in Leadville, Colorado, in 1877. From that time, pyritic smelting has been chiefly developed by American metallurgists. The metallurgy of lead, copper, and zinc has reached a similar high plane to that attained by iron and steel.

The metallurgy of gold and silver began to improve after the discovery of the Californian deposits in 1848. The stamper battery and amalgamation processes were improved; when sulphide ores were encountered, chlorination processes were developed. Subsequently, in response to demand for a cheaper chemical solvent for low-grade ores, the cyanide and bromide processes were devised.

The application of the electric furnace to metallurgy greatly increased the scope of metallurgists' methods.

Pichon, in 1853, described a small arc furnace with which he was experimenting, and in 1878 Sir William Siemens built a furnace for reducing iron ores. Moissan made numerous tests of furnaces and smelting methods in the nineties and did much to develop commercial electric smelting. Faure, Cowles, Borchers, De Chalmont, Girod, Heroult, and others invented furnaces, smelting methods, and metallurgical processes. The aluminum, carborundum, acetylene, and other important industries



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EDOUARD BELIN AND THE TELAUTOGRAPH, WHICH TRANSMITS PICTURES BY WIRE

LEE DE FOREST, INVENTOR OF THE OSCILLATING AUDION

AUTOMOBILE WITH RADIO EQUIPMENT FOR LISTENING IN EN TOUR are developments from the electrometallurgy of iron and copper. Zinc, copper, nickel, silver, gold, and platinum plating and the electrodepositing of copper in the form of tubes by the Elmore process are dependent upon the principles of electrometallurgy as is the electrorefining of metals.

The physical phenomena of the earth's atmosphere are studied under the science of meteorology.

The art of weather forecasting is as old almost as mankind, but only in recent years has it been placed upon a sound basis.

Torricelli, in 1643, invented the barometer; Boyle, in 1685, developed it and applied it to measuring gas pressures. The chemists of the eighteenth century, Boyle, Black, Rutherford, Priestley, Scheele, Lavoisier, and Cavendish, all studied the chemistry of the atmosphere. Franklin, in 1749, raised thermometers by kites to measure temperatures. Balloon ascents were made by Jefferies and Blanchard, in 1784, for atmospheric observations. Soundings of the upper air by balloons, kites, and other apparatus have been conducted since the closing years of the nineteenth century.

CHAPTER XV

MEDICINE AND PHARMACY

MEDICINE was in a state of transition at the beginning of the nineteenth century. The great scientific discoveries of the eighteenth century had carried people away to such an extent that they showed a tendency to exaggerate their bearings upon medicine. The result was a wild diffusion of extravagant speculation and unsubstantial hypotheses.

One of the leading physicians of the eighteenth century, who wielded broad influence throughout Europe, was Herman Boerhaave (1668-1738). His work, entitled "Aphorismi," published in Leyden, 1709, was immensely popular. It was translated into all the European and several Asiatic languages. His reputation now depends upon his chemical discoveries and his medical teachings.

One of the most brilliant students of Boerhaave's medical school was Albrecht von Haller (1708-77). Haller published many medical works and monographs. His "Elements of Human Physiology," (1759-66) is the best known. The function of bile in the digestion of fats, the demonstration of Glisson's hypothesis that irritability in an excised muscle is a specific property of all living tissues, and several theories explaining the heart's activities, were among his best contributions to medical science.

The discovery of the existence of lacteal and lymphatic vessels in birds, reptiles, and fish brought William Hewson into prominence and secured him membership in the Royal Society. He published his monograph on the coagulation of the blood in 1771.

William Cumberland Cruikshank (1745-1800) investigated the surgery of the nerves, the functioning of the Fallopian tubes, the physiology of absorption.

The electrical discoveries of Galvani, Volta, Benjamin Franklin, Henly and others caused much experimenting with the electric current in the treatment of muscular diseases.

The Monros, father, son and grandson, by their wonderful teaching abilities, caused the medical teaching center of Europe to be transferred from Leyden to Edinburgh in 1720. These men, and many of their students, did brilliant work in all branches of medicine.

The medical school which they so established in Edinburgh University still maintains its great reputation.

The best anatomists of the eighteenth century were Cheselden, Pott, the Monros, the Hunters, Desault, and Scarpa. Their work was largely topographical. Surgical anatomy started with the writings of Joseph Lieutaud (1703-1780), Albinus, Eisenmann, Soemmering, Mascagni, Sandifort, and Caldani.

The anatomical textbooks in use in the year 1800 gave general accounts of the body's structure and included current theories of the functions of organs and their relationships to injuries and disease. More than half of the chapters were occupied with morbid anatomy and the recital of cases. The anatomy of the tissues and finer structures was neglected because the microscopes of the period were little better than simple lenses.

Physiology was studied by all medical students, but the science was so badly developed that it never stood alone. For many years it formed a part of studies in anatomy. Early in the nineteenth century it began to expand, and in 1846 physiology was taught as a separate subject for the first time at Guy's hospital, London, by Sir William Gull. Before that it was taught by the professors of midwifery. It was the great developments made in chemistry and physics, referred to in previous chapters, that pushed physiology to the front as an important branch of medical science.

Denman's "Introduction to the Practice of Midwifery," the work of the greatest living authority at the time of its publication in 1805, shows that gynecology hardly existed at that time.

Anesthetics and antiseptics, together with the systematic employment of abdominal and bimanual palpation, all were revolutionary discoveries of the nineteenth century, unknown when Denman presided over the obstetric department of the Middlesex Hospital.

When the nineteenth century opened, medical men were unaware of the value of auscultation and percussion. They were familiar with the symptoms of fevers and with diseases of the heart and chest, but they had no means of determining differences between them. Textbooks of that time show that the now common forms of heart disease were known only from post-mortem inspections. But they distinctly state that physicians were unable to determine, in case of changes in stricture of the heart's valves, what part was affected. The seat of disease in heart and chest troubles could not be located.

Parasitology was no better advanced. Books published as late as 1810 indicated that parasites, like hydatids, threadworms, etc., were very puzzling phenomena to the physician.

The status of surgery throughout the eighteenth century was very low. The best work was done in France and Holland, until Cheselden, the Hunters, the Monros, and Abernethy established their schools in England and Scotland. German medical practitioners were barbers until after the army authorities formed the Medico-Chirurgical Pépinière in Berlin in 1785. There were several good medical schools in the United States in 1800 including those of the King's College, New York, and of the Harvard, Dartmouth, and Philadelphia Colleges, and the University of Pennsylvania. There were also numerous medical societies. European medical and surgical textbooks were used like those of Cheselden, Monro, Haller, Boerhaave and Sydenham. Medical practice was on the same plane in America as in Europe. There were many patent remedies used, but the authorities recognized the importance of regulating the practice of medicine. Regulation acts were passed in New York City in 1760, New Jersey in 1772, and a general quarantine act was enacted by Congress in 1799.

The modernization of medicine was brought about to a large extent by the publication of the "Conservation of Energy" by Helmholtz, in 1847, and Darwin's "Origin of Species," in 1859. These books cleared away completely the myths and legends which had surrounded medicine at earlier periods, and taught medical students the strict need of proceeding entirely upon scientific grounds precisely as chemists, physicists, engineers, and others were already doing with wonderful success. Darwin's biological teachings appealed very strongly to medical men and influenced all their activities.

Virchow's "Cellular Pathology," published in 1858, Huxley's textbooks on "Physiology" (1866) and on "Vertebrate and Invertebrate Anatomy" (1871-77) Haeckel's "General Morphology" (1866), and numerous medical encyclopedias and textbooks on practice and special diseases were the result of the new scientific spirit. New medical associations were formed and these promoted discussions, the reporting of observations, and the publication of innumerable monographs. Medical journals and magazines of a high character did fine educational work.

The investigations on fermentation and putrefaction made in France by Pasteur caused Joseph Lister, professor of surgery at Glasgow University, to reflect upon the great mortality witnessed daily in the hospitals from pyæmia, erysipelas, tetanus, septicemia, gangrene, and other similar diseases. He observed that in spite of his great care to maintain scrupulous cleanliness in treating wounds, 45 per cent of his surgical cases were mortal. Pasteur's dictum that putrefaction is a microorganic phenomenon, caused Lister to experiment with the view of preventing the development of microorganisms in wounds. Beginning with weak solutions of zinc chloride and zinc sulphite, he accidentally tried carbolic acid, securing surprising results, and two years later, in 1867, he published his monograph on antiseptic surgery which instantly became world-famous. Lister, instead of being carried away by the celebrity he attained, turned his attention to the scientific development of his important discovery. He investigated lactic-acid fermentation, the relation of bacteria to flesh inflammations and to the best methods of treating wounds antiseptically.

Lister, however, was not the first to employ antiseptics in the treatment of wounds, and his great contribution to medical practice was due to the systematic manner in which he experimented. He was not a brilliant surgeon, but a deliberate and careful one whose chief desire was to have the patient recover. His whole surgical career was guided by this principle which proved so successful that before his death the whole medical profession saluted him as master, and when he died, rejoiced that his remains were entombed in Westminster Abbey.

Theodor Billroth was one of Lister's greatest disciples. He introduced Lister's methods into continental surgery and through their use improved the treatment of wounds and opened up new fields in the surgery of the alimentary tract. He was the first to make a resection of the esophagus and pylorus and to excise the larynx.

Mikulicz-Rodecki, a Pole, was Billroth's chief assistant. He was also a pioneer in Lister's practice. Specializing on the surgery of the alimentary organs, he promoted antiseptic methods and introduced the modern modes of exploring the esophagus and stomach. He was also a master in the treatment of diseases of the mouth.

Felix Guyon applied Lister's system to surgical treatment of the genito-urinary ailments, and became a leader in this class of surgery. Bernard Naunyn, a well-known German writer on surgery, became a leading authority on diabetes and diseases of the liver and pancreas. Jean Martin Charcot made the Salpêtrière Hospital, Paris, the greatest of the world's neurological clinics. He was also a great authority on diseases of the biliary passages and kidneys. Sir James Paget, Sir Jonathan Hutchinson, Sir William Gull, Jenner, Wilks, Spencer Wells, and Clifford Allbutt, besides doing much by their writings to advance the practice of medicine, all closely allied themselves with large hospitals, giving as much attention to the hospitals as to the treatment of disease. Modern hospitals are largely due to their pioneering work.

Louis Pasteur's studies in fermentation led to the discovery of lactic-acid bacteria and this was the starting point for a number of revolutionary discoveries in bacterial diseases. Infectious diseases were placed in new categories by his work.

The etiology of traumatic infectious diseases was advanced by the researches of Robert Koch (1843-1910). His work in discovering the cholera vibrio, the microorganisms of Oriental ophthalmia and his researches on the nature and treatment of tuberculosis, made his name known everywhere. His isolation of the tuberculosis germ in 1882, and that of Asiatic cholera in 1884, were leading steps toward the discovery of a great number of disease germs.

Fevers, like typhus, typhoid, yellow fever, and malaria, a few generations ago, took a great annual toll of lives. The work of the men mentioned above, Lister, Pasteur, Koch, and the French physiologist, Claude Bernard, gave medical men the means of curbing the ravages of these diseases so that to-day they are incidental annoyances rather than human scourges.

The germ of typhoid fever was discovered in 1880 by Eberth. The cocci of pneumonia were isolated by Frankel in 1886.

Modern surgery has been greatly facilitated by the employment of numerous anesthetics, chemicals which possess the power of inducing local or general insensibility. Soporific drugs have been used in surgical operations since the remotest antiquity, but modern practices in the employment of anesthetics followed the discoveries of Faraday in 1818. He described the properties of nitrous oxide, or ether and other gases in that year and suggested their use in medicine.

John Godman (1822), James Jackson (1833), and Drs. Wood and Bache (1834) were among American medical men who made use of Faraday's suggestions. Dr. Horace Wells, a dentist at Hartford, Connecticut, used ether in 1844. Two years later W. T. Morton, a dentist in Boston, employed it successfully. Chloroform was described as a useful anesthetic by Dr. Flourens, of Paris, in 1847, the year in which Sir James Simpson introduced ether as an anesthetic in obstetric practice.

Mesmer introduced hypnosis into medical practice about 1777, and in 1784 Benjamin Franklin reported favorably on the medical value of what he called magnetic sleep. Alexandre Bertrand, about 1831, described the nature of hypnosis and in 1841 James Braid employed it in his English medical practice. The employment of hypnosis has not become general, although it is recognized that in certain nervous troubles there is a field for it.

Among other American medical men who advanced their science in the past were James Marion Sims (1813-1883) and Thomas Emmet, who acquired wide fame for successful methods of operating in obstetric diseases. William Beaumont (1785-1853) investigated the offices of the gastric juice and devised treatment for digestive troubles. John Shaw Billings served his profession by compiling, with the assistance of Robert Fletcher, an Index Catalogue of the Surgeon General's library, Washington.

Pharmacology is as old as medicine. The medicinal qualities of herbs, roots, and gums were known to primitive man. There have been herbalists and druggists in all important communities at all times. Scientific pharmacology, however, is just as new as modern medicine. Cordus published a pharmacopœia, which listed drugs in use in 1535. Since that time many such works have appeared. The second of the Monros of Edinburgh University Medical School, Magendie, and Claude Bernard placed pharmacy upon a scientific basis. They followed scientific methods used by Fontana in Florence in 1765 in studying the effects of snake poisons. Pareira's "Elements of Materia Medica" was the leading textbook in 1842. This work gave very brief accounts of the physiological effects of drugs. The physiological values were not properly appreciated until about twenty years later.

Drugs are now scientifically classified and prepared, the full resources of science being used in their manufacture. American chemists have invented machinery and methods of preparing new drugs. Citrate of magnesia was invented by Henry Blair, of Philadelphia. Many other valuable remedies came from his laboratory, including sirup of phosphates.

CHAPTER XVI

ELECTRICITY AND RADIOACTIVITIES

AMONG the most marvelous scientific developments of the nineteenth century those in the electrical field claim universal attention. It was only as recently as 1844 that Morse introduced electric telegraphy. The telephone was introduced by Alexander Graham Bell in 1876 and Edison built one of his early dynamos in 1878 and in 1879 made his first high resistance incandescent lamp for parallel operation. The first Edison power and lighting station was opened at 257 Pearl Street, New York City, in 1882.

Although electrical phenomena were understood in a general way thousands of years ago, they were not studied and applied to practical purposes until the sixteenth century when William Gilbert carried out his classical experiments in the reign of Queen Elizabeth. The Leyden jar was discovered in the early half of the eighteenth century. From experiments carried out with these jars a great number of important inventions were derived and our knowledge of electricity was for many years dependent upon researches of this kind. Benjamin Franklin in experimenting with the Leyden jar found that its electrical discharges were similar to those of lightning and he subsequently discovered that the inner part of the jar, when charged with a frictional current, was positively electrical while the outer portion was negative.

The voltaic pile was invented in 1796 as a result of Galvani's experiments in physiological electricity and Sir Humphry Davy exhibited the first practical electrical lamp before the Royal Society in 1809. The dynamo was, in substance, invented by Faraday, and described by him before the Royal Society in 1831. This was, perhaps, the greatest of all electrical triumphs because it gave engineers a practical means of generating and using electrical currents of any desired dimensions. Bunsen in 1840 devised a means for making carbon rods for arc lamps, and Edison made practical carbon incandescent lamp filaments in 1879. Faraday's invention promoted all of these lighting discoveries.

The engine-driven electric dynamo was made a practical machine in 1870 and thenceforward became the source of power of a great multitude of secondary machines, such as electric street cars, marine engines, power plants, and forging hammers.

A new and profitable field was opened for the use of electricity by the invention of the electric furnace. Sir Humphry Davy produced his electric arc in 1808 and was greatly impressed with its fusing properties. He melted many metals with the arc and found that it fused platinum just as easily as an ordinary tallow candle melts beeswax. The electric furnace, which is now extensively used in chemical and metallurgical works, is simply a large electric arc provided with means for containing the heat. Furnaces lined with carbon are now heated to over 4,000 degrees centigrade.

When the electrical manufacture of aluminum on a large scale was started at Niagara, Dr. Edward

Acheson, who was impressed by the industrial needs of cheap abrasives, accidentally discovered that by heating a piece of porcelain to a high temperature in an electric furnace and bringing it in contact with pure carbon, the carbon was rendered very hard. In 1891 he carried on experiments with high currents and a mixture of ground coke and sand. He found a method of fusing these so that the oxygen of the sand passed off with carbon in the form of carbonic acid gas, and the reduced metallic silicon combined with an equal atomic weight of carbon and produced a new body which he named carborundum. The success met with in making carborundum led to the devising of a method of manufacturing artificial graphite in the electric furnace. A soft, non-coalescing graphite was made in 1906. This is extensively used in lubricating heavy machinery.

Dr. Acheson produced the first chemically pure artificial carbon in his electric furnace in 1911. By using pressure during consolidation this carbon may eventually be converted into diamonds.

Another valuable product of the electric furnace, acetylene gas, was discovered in Dublin by Edmund Davy in 1836. Subsequently numerous chemists discovered means for making carbides. T. Sterry Hunt, an American chemist, observed in 1886 that oxides of the alkaline metals and of calcium, magnesium, aluminum, silicon, and boron could be reduced in the electric furnace in the presence of carbon and could be alloyed with other metals. He also found that silicon and acetylene could be made that way.

T. L. Wilson, a Canadian engineer, in attempting to make aluminum bronze in an electric furnace, devised an experiment for reducing lime with carbon. He found that this produced calcium carbide and secured a patent for the invention in 1892. Variations of this process are now used for manufacturing nitrogen and nitrates from atmospheric nitrogen.

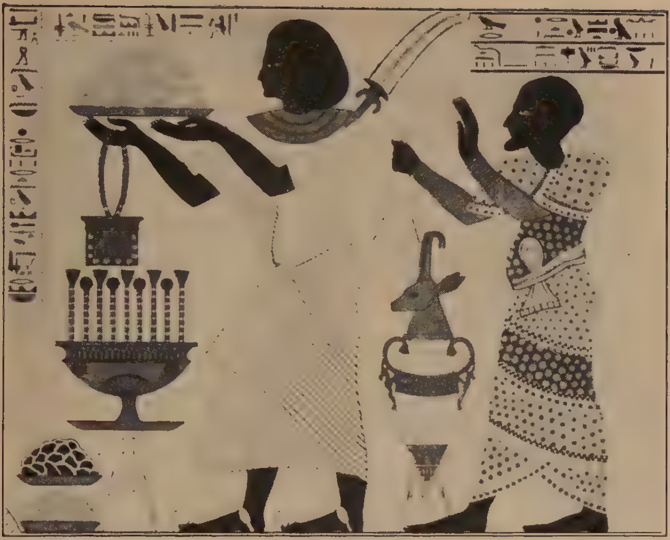
Wireless developments have resulted from the work of many separate investigators. K. A. Steenheil in 1838 used the earth return in live telegraphy and suggested the possibility of wireless telegraphy. Joseph Henry produced the first high-frequency oscillations in America in 1840. Lord Kelvin in 1853 enunciated the mathematical principles governing uncoupled electrical oscillatory circuits. Joseph Heyworth patented a wireless telegraphic process in 1862. Clark Maxwell in 1867 predicted the existence of electromagnetic radiations and these were demonstrated by Hertz in 1887. Hughes discovered the phenomena of the coherer and Branby used Hughes's coherer for wireless wave detection in 1892. A. E. Dolbear secured United States patents for a system of wireless telegraphy using aerials in 1886. Sir Oliver Lodge described his wireless system before the Royal Society in 1894 and in the same year Popoff issued descriptions of his wireless system.

Wireless telegraphy became commercially practicable in 1897 when G. Marconi secured the promotion of the Wireless Telegraph and Signal Company in England. Marconi succeeded in turning to commercial account a long series of brilliant discoveries in electricity, and this success has led to numerous kindred discoveries. De Forest's three-electrode thermionic detector, known as an Audion, invented in 1907 and improved in 1911 by Lieben and Reiss, in 1913 by Meisser and in 1914 by Langmuir, opened up great possibilities for sound transmission by wireless telephony.

The electric deposition and refining of metals have been referred to in previous chapters. Many industries are based upon these. Niepce produced commercially successful photographs in 1838. Earlier, in 1824, he had etched plates for printing and in that year published his photo-engraving of Cardinal d'Amboise. Fox Talbot patented a mixture of gelatine and bichromate of potash to take the place of the bitumen used by Niepce as a plate coating. Gillot found in 1872 that Fox Talbot's method of making intaglio plates could also be used for making relief blocks. In 1885-1886, F. E. Ives sealed two single-line screws together and made a new fine cross-line screen, which resulted in the development of the half-tone process. Ives at this time also developed the three-color photo-engraving process.

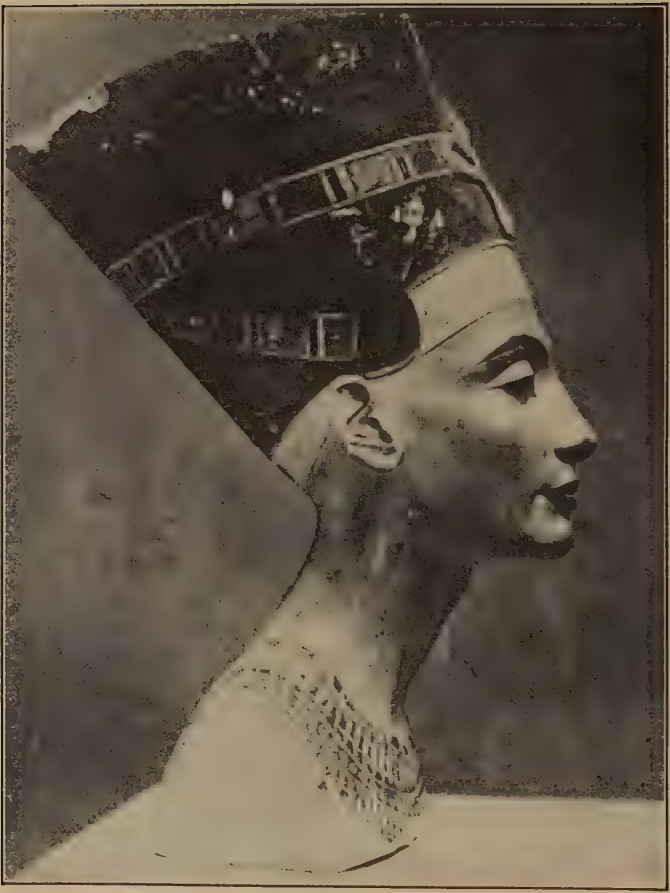
Photography and photo-engraving are so widely used and are so intimately connected with our civilization that few people now realize that the great industries based upon them are the results of a few scientific discoveries of a couple of American and European scientists made only a generation or two ago.

Chemists had long recognized the fact that certain chemicals like preparations of zinc, fluorine, and phosphorus were phosphorescent. It was found early in the eighties that Welsbach gas mantles, when placed on a photographic plate and exposed in a dark room for two weeks, made a fine picture. Invisible rays in the mantle imprint its image. Röntgen, in 1895, discovered what are now known as the X-rays. This discovery was the result of ex-



GIFTS FOR TUTANKHAMEN BROUGHT BY HUY, VICEROY OF ETHIOPIA. THE MAN IN THE GAY COSTUME, AT THE RIGHT, MAY BE A PHOENICIAN. (EGYPTIAN PAINTING)

TUTANKHAMEN'S TOMB—BRINGING UP THE HATHOR COUCH. THE COW WAS SACRED TO ISIS OR HATHOR OF WHOM THE HORNS WITH THE MOON DISK WERE EMBLEMS



QUEEN NEFERTITI, MOTHER-IN-LAW OF TUTANKHAMEN

This wonderful work of an unknown Egyptian sculptor represents the wife of Ahknaton, the "heretic" king of Egypt (originally Amenhotep or Amenophis IV). The original is now in the Berlin Museum.

periments begun in 1859 by Plucker to ascertain the cause of fluorescence in light glass, and Sir William Crookes, between 1879 and 1885, carried out beautiful experiments on fluorescence. These were the immediate pioneers of the discovery of the cathode rays and the other great radio discoveries of recent years. Crookes, remembering Faraday's suggestions concerning a fourth state of matter, expressed the opinion, in 1885, that the matter constituting cathode rays is neither solid, gaseous, or liquid, but in a fourth state which transcends the gaseous condition. Perren found in 1895 that the rays carried electrically negative charges and Sir J. J. Thomson noticed that their velocities are appreciably less than the speed of light. Owing, however, to their great momentum, hardly anything can long endure their impacts. They fuse platinum and make diamonds buckle up into coke.

Electrons, which constitute the cathode rays, were originally studied in Crookes vacuum tubes, though they are now found to pervade the universe.

Larmor in 1897 proposed an electronic theory of magnetism.

Henri Becquerel was the first to discover radioactivity. He made radiographs from uranium salts in 1896. M. and Madame Curie undertook the investigation of uranium and found that among the minerals occurring in pitchblende, or uranium ore, bismuth and barium showed radioactive properties, whereas when these metals are found in their ordinary ores they are not radioactive. This discovery led to the finding of two new metals, polonium and radium. Radium is now obtained by fractional distillation of solutions obtained from American and Australian pitchblende.

Helium, one of the lightest substances known, was discovered in 1895 by Sir William Ramsay, and liquefied, at a temperature 3 degrees above absolute zero, or —270 degrees centigrade, by Onnes in 1908. Helium appears to be one of the ultimate products of the disintegration of all radioactive elements.

Some of the most interesting discoveries about radioactivity are very recent. Radium prepared from uranium in 1915 was found in 1919 to have increased proportionately to the square of the time interval. The amount of radium in some preparations was found to have increased ten times in four years. The old idea of the constant fluxation of matter was thus shown to have been based upon a scientific truth.

CHAPTER XVII

SCIENCE IN THE TWENTIETH CENTURY

IT is obvious that we are now in a great period of transition. Scientific discoveries came so quickly at the end of the last century that a recasting and readjusting of scientific conceptions had to be undertaken. This process was in progress when the World War began. The world-wide disturbance led to temporary scientific infertility except in such directions as served the purposes of war. But therein science became allied more closely than ever before with certain branches of industry, and the cooperation thus established has been recognized in all civilized countries as of the utmost value to the future progress of mankind.

The philosophic thought of each era generally develops in harmony with social and intellectual conditions. The philosophical doctrines of the leading writers may, therefore, be taken as representative of the spirit of their age. When Darwin in the middle of the last century published his doctrines of evolution, of the struggle for existence and the influences of living conditions upon survival of species, philosophy turned away from the utilitarianism and tolerance of Hamilton, Hume, and Mill and the positivism of the French to the synthetic evolutionism of Herbert Spencer. One of the basic teachings of Spencer was the relativity of knowledge. The process of thinking involves relation, difference, and likeness. This is merely relationing. Therefore no thought can ever express more than relations. The primary act of thought through which we discover likeness and difference underlies all our knowledge.

A reaction against this new empiricism began in 1898, when William James published his "Philosophical Conceptions and Practical Results." This work popularized the philosophy of pragmatism which denies the absoluteness or ultimateness of the traditional antithesis between theory and practice and relies for its justification upon the fact that everything which we think about, and do, must first be willed. Reality consists in pure experience quite independent of thought. Bergson developed this philosophy of practicalism further and taught that knowledge of reality comes through intuition and that life is merely intuitive knowledge. Intuition, is deeper than scientific reason because it feels, and links us with, the eternal processes of nature.

Philosophic thought is now temporarily influenced by the revival of an old principle known as the principle of relativity. The popular name for this is the Einstein theory, because in 1905 Albert Einstein, working on some theories developed by Lorentz and Fitzgerald, published his first principle of relativity which suggested that the velocity of light is constant, however the position of an observer may vary and that space and time are variable. In 1917 Einstein enlarged this idea in order to include all the laws of nature.

Space and time are treated as just mental concepts. They lack the concreteness of matter, but they compose the framing of the universe and give it form and continuity. Consequently we see so much of them that we attribute reality to them. The theory of relativity suggests that time is not continuous. There is no identity of instants at different places. The present instant really does not extend beyond this immediate point. At other points there are instants older, younger, and contemporaneous with this instant. They are, how ever, quite distinct from this one. In order for an instant to be simultaneous it would be necessary that it should occur at the same point.

An object or event gains its substance and form from activities of our minds. Any meaning or significance that an object or event has is also derived from our minds. The reality of the universe is an activity, or series of activities, which are manifested in life and mind.

The relativity of space is illustrated by an example given by Professor Henri Poincaré. Assume that I meet you in Wall Street, New York, and say, "I will meet you here again at this time to-morrow." You promise to do so. But you could not keep such a promise except with regard to position on the surface of the earth, because between now and to-morrow the earth will have moved over an enormous distance carrying Wall Street and a great mass of other things with it. The sun also will have moved away the stars, carrying the earth with it.

Another interesting mental picture is drawn by Professor Herbert Wildon Carr to illustrate the philosophical meaning of the principle of relativity. Suppose that on a very frosty morning we were to see a watery vapor in the air we breathe condense into a little cloud and after floating around a while gradually disappear and become reabsorbed in the atmosphere. Assume that at the moment of this reabsorption we should undergo an instantaneous transformation of all our proportions so that our new dimensions become infinitesimal in comparison with our former state. Do you think that we would recognize the fact that we had changed? The theory of relativity declares that we would not know what had happened, because with the alteration in proportions the ratios would remain constant. The change would express itself in the new dimensions of objects around us. The little globules of water composing the little cloud would now appear like stars and planets occupying immense areas in distant spaces, far apart from each other, and all undergoing a slow age-long evolution. Such a change would be signalized as a new time and a new space.

Yet the principle of relativity does not appear to our physical senses to represent a truth of nature. It is noteworthy that the principle of relativity is usually invoked when conditions are unstable, when thought is confused, and when a period of readjustment is in progress. Thus the Einstein theory may be representative of present-day harmonies, but yet may prove, in the future, to have been merely a passing philosophic mood.

Bagehot, a shrewd observer, writing in 1868 about the changes wrought by Darwin's evolutionary theory, said: "There is scarcely a department of science or art which is the same, or at all the same, as it was fifty years ago. A new world of inventions has grown up around us which we cannot help seeing; a new world of ideas is in the air, and affects us though we do not see it." Those were very true words more than half a century ago, yet they serve to describe present conditions!

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